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ABSTRACT

This report contains the three position papers presented at a conference on interdisciplinary science education as well as edited transcripts of some of the discussion. The position papers state the necessity for such courses, describe a particular college level course for non-science majors, and present a theoretical account of an attempt to classify all knowledge in a single pattern. The excerpted discussion episodes deal with problems of definition, of recognizing the characteristics of interdisciplinary teaching, of implementation of secondary school or college levels, and of tactics to be used: whether to modify existing conditions or state de novo. Discussion group reports on teacher education, task force models, and the breadth of unity are included. Participants' names and addresses are listed. (AL)

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SUPPLEMENT

INTERDISCIPLINARY SCIENCE EDUCATION

Report of a Conference

INTERDISCIPLINARY SCIENCE EDUCATION

Report of a Conference

Washington, D.C., January 23-26, 1969
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Leo Schubert, Conference Director

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REPORT OF A CONFERENCE ON INTERDISCIPLINARY SCIENCE EDUCATION

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INTRODUCTION

THE last few years have witnessed an acceleration of interest in changes in science programs at all levels. Among the contributing reasons is the apparent failure of the formal courses, particularly at the college level, in attracting the support of non-majors in the discipline. With the increasing tendency at the college level and in the secondary schools toward elective rather than required general studies, it is becoming increasingly clear that nonscience students will not elect the traditional courses in science. This not only affects science programs but also the very nature of our culture. I. I. Rabi titled his recent book *Science: The Center of Culture,* and this is a reminder of the Georges Sarton title *Science: The New Humanism.*

While many proposals and some action have been advanced to acquaint students with the role of science in a scientific culture, one of the recurring threads has been the development of interdisciplinary programs in science education. The American University, with support from the National Science Foundation, undertook to sponsor a conference on "Interdisciplinary Science Education" during January 23-26, 1969, in the hope that such a conference would act as a gadfly to encourage greater interest and action in developing interdisciplinary programs.

Three position papers were presented. These papers served as anchors for the discussions. The participants were representative leaders in science education, and the scientific societies were well represented. Because of the wide spectrum of participant interest, ranging from those clearly committed to interdisciplinary science programs to those more concerned with individual disciplines, it was hoped that the outcome might provide a useful augury for the future of interdisciplinary science education.

Reasonable consensus was achieved. The desirability of interdisciplinary programs on the secondary and college levels was affirmed and suggestions for action were made. It is hoped that this report might serve as a foundation for such action.

As the Conference Director, I wish to offer my appreciation to the participants for their commitment, courtesy, and knowledge; to the National Science Foundation and its representatives for their support; to the National Science Teachers Association for its editorial work and the publication of the proceedings; and to The American University for sponsoring the conference.

LEO SCHUBERT

INTERDISCIPLINARY SCIENCE EDUCATION: A POSITION PAPER

Albert Szent-Györgyi

WE have come together to talk about interdisciplinary principles and to build bridges between the different branches of science. In my opinion, such discussion is hardly needed, because the various disciplines have already fused into one big body of knowledge, one great new central science, though as yet it has no name. One might call it "nature study" or "natural philosophy." Our concern should be to avoid dismembering this unit; we must not divide it into separated subjects.

The different sciences into which we subdivide nature are artifices which owe their existence to our shortcomings, to our inability to visualize complex phenomena as an entity. If I go out into nature, I do not see physics or chemistry anywhere. What I see is light or darkness, rocks or clouds.

Sciences, like children, go through various stages. The first is that of collecting data. The second is that of dividing phenomena into groups which we may call physical or chemical until, eventually, we are led to a deeper understanding, to principles which connect the apparently isolated phenomena—and chemistry becomes atomic physics, or physics becomes mathematics.

There is no need to take our students through this long struggle. Having reached this understanding and generalization, we can start from there and work backwards. I recognize that data are necessary and that one reaches principles through data, but data, in themselves, are boring and meaningless. They serve only to lead us to principles. If we start with the principles, the data become alive and interesting.

Dr. Szent-Györgyi conducts research at the Marine Biological Laboratory, Woods Hole, Massachusetts, and is Professor of Biology at Brandeis University. He received the Nobel Prize for medicine in 1937.

In spite of its enormous growth, science is easier to teach and is more interesting today than it has ever been, because it has led to principles which connect the data and single phenomena.

This unification of knowledge is the greatest achievement of science and, perhaps, the greatest achievement of the human mind. We understand the sun since we understand the atom. We start teaching medical students by teaching them the structure of matter and build from there.

What I would like to see taught in school is this new subject—nature, not physics and chemistry. The question then arises: How we can tackle such a complex subject? Faraday gave one answer when he talked to children about a candle. He did not talk about the physics or chemistry of the candle, but talked about the candle and slowly led the children into its chemistry and physics, fascinating his audience. I would take children out into nature and look around, then, say, pick up a stone, and then let it fall. The weight of the stone and its fall would lead me into gravitation, the forces holding our solar system together. Then I would perform Galileo's famous experiment and drop a big stone and a small stone and see them reach the ground simultaneously. I would also throw a stone which would lead me into mechanics, to force, momentum, and inertia. I would follow up by putting a piece of limestone into hydrochloric acid and see it dissolve, which would take me into chemistry and eventually to its center, the table of Mendeleev. There is nothing one can not explain to children, if one can preserve the child-like simplicity and naïveté of one's own mind. With such a direct method, one could not only explain nature but make it absorbingly interesting, gradually working one's way up to biology and living things. One could give a really deep insight into nature's workshop.

I would like to consider now another unit, repeating again that we must not break it up. This is the unit formed by science and humanities, and there has been a trend to separate science from humanities. There is even talk about "two cultures." I think that this is a mistake based on a lack of understanding. There are no two cultures. Culture is one, by definition. It is said that science does something to nature and humanities does something to the mind. Science does nothing to nature: It just opens up man's mind to it. There always were atomic reactions, but the human mind learned about them only lately. Many problems, such as those of space and time, which belonged to the realm of philosophy a short while ago, now belong to the sciences. The border line between science and philosophy shifts continuously, with science engulfing more and more of the problems of philosophy, making one single unit of the two lines of thought. If science is no part of philosophy and humanities, it is not science but technology. Just as we scientists cannot live without philosophy, so the humanist cannot live without science and the scientific methods on which it becomes more and more dependent. With our deepening knowledge, all borderlines become increasingly hazy. I would not regard anybody as a humanist who has no idea of where he is and what he is. In a way, science is itself a humanistic subject. Science and the study of social relations have fused in "social science." Science and politics have fused to "political science." Humanists like to picture science as something inhuman. Science is very human. It is a human endeavor to understand, and it is not devoid of moral values. Do not cut off science from humanities or *vice versa*.

It may be claimed that one of the main subjects of humanistic culture is history, which has nothing to do with science. Should this be so, it would signify a great shortcoming of history, and it is urgent that this be corrected. What is history, the real history of man? It is the story of man's slow rise from his animal status, the story of how the level of his life gradually improved, giving a chance for his mind to open up to beauty. Though I am a scientist, I consider history the most important subject in school, because it is the only subject which helps us to establish a scale of values which dominates all our life and actions. But, to be able to do this well, provide such a scale of values, it must be real history—not that shallow story of wars, peace treaties, shifting borders, and the like, which is not only meaningless but even deceitful. Deceitful, because, as Zinsser showed, most wars and battles were not decided by glamorous kings or generals but by rats and lice which spread disease.

Man is small, nature is big, and so it follows that the level of human life has always depended on the measure to which man understood nature and could use its forces to his advantage. Human history, essentially, is the history of the knowledge of nature; that is, science. The needle, the wheel, fire, and classical and modern science are the great signal stations of human history.

The slowly rising line of human life is the resultant of two forces, the one pulling it up, the other pulling it down. The representatives of the upward-pulling force are the great minds who found new knowledge, new ethical and moral principles, or new beauty. These are the real heroes of mankind. The representatives of the forces pulling us down are the generals, kings, and politicians, who made wars, destruction, and misery, separating man from man, leaning on violence and brutality, leaving behind mostly ruins. The history I learned in school was filled with the names of these men and the meaningless shifting borders they created, while the names of Newton, Darwin, Pasteur, Bach, or Rembrandt could be found nowhere in my textbooks of history.

A real history would engrave correct ideals into the developing mind along with a respect for knowledge and moral values, which are more and more missing in our public life. This balance of destruction and construction, violence and knowledge, is the backbone of history. I can even imagine a complete fusion of the teaching of science and history. What we should teach as history is the story of man's widening mind, his increasing knowledge, starting with his utterly primitive life of 100,000 years ago, and following him step by step as he gradually learned to understand the world around him.

If I were teaching history, I would try to bring my pupils into the mentality and conditions of the different ages and let them make the signal discoveries themselves, let them see what the knowledge meant, and how it improved and elevated life. This would give a new value judgment and at the same time would be a good didactic method. The primitive life of our ancestors would be the subject for the younger classes and would appeal to the child's mind. Our teaching of the gradual sophistication and expansion of knowledge and improving human relations would be parallel to the mental development of our schoolchildren. Eventually, in the highest grades, we would reach the latest developments and the appearance of modern science which changed the face of human life.

The essence of what I am trying to say is: Don't divide natural units, don't divide science and history. But, there is also another important thing I would like to say, and this is that we shouldn't *teach* children, but let them *live* things, let them live through everything, avoid cramming and book knowledge. They forget later anyway what they have learned. What they can and should retain for all life is the love of learning and knowledge, the excitement of knowledge. To illustrate this with an example I would recall a visit to the Shady Hill School in Massachusetts, some thirty years ago. The school was founded by an old Harvard professor who became dissatisfied with the methods by which his grandchildren were being taught, and I do not know whether the school still exists and has kept its vigor. On my visit in the thirties, I saw three classes. In one the children were learning about the Trojan war. They rebuilt Troy from clay and followed the battle from street to street. I never forgot how excited these children were. It was there that I myself began to understand the Trojan war, on the study of which I spent several years of my youth. The second class was on Nordic Culture, and the children made weapons, jewels, and ornaments out of cardboard and paper and lived like Norsemen and Vikings, getting a real idea of what that culture and life was like. The third class was a music class where children "lived" music and followed its rhythms and moods with the movements of their bodies. They lived things instead of learning them.

Such learning touches one of our central problems: What is the aim and meaning of teaching and education? If we want to get somewhere, the first thing we have to know is where we want to be. What sort of individual do we want to produce? One of the greatest problems of a modern society is that it can produce more than it can consume, and boredom becomes a terrible enemy of man. At present we have to go to Vietnam and kill people to relieve our boredom and destroy what we produce. This is not a good solution. The good solution is producing men who have their eyes on wide horizons, who have an appreciation of human values and knowledge, and know what to do with themselves, men who know and understand where and what they are, who are not the servants but the masters of their own creations.

I would like to see someone write a textbook of world history, of real world history. Such a textbook does not exist. As a schoolboy, I learned "Hungarian World History." Americans, I suppose, learn "American World History." A real world history would inculcate that feeling of human solidarity, the lack of which carries us towards the brink.

I have talked about various unities. I would like to finish with mentioning one more: the unity of teaching and education. Teaching is looked upon as a cerebral function while education concerns the character. They are one single unit. As the brain cannot be separated from the body, so teaching cannot be separated from education and should not be separated from it. Teaching must educate, and education must teach, to lead to the product we want, to produce a *man*.

This has always been important, but it is of vital importance today when, owing to the rapid growth of modern science, practically all our ideas and institutions connected with politics and human relations have become antiquated, and a new world must be built. Our present youth will have to do the rebuilding.

CREATING AN INTERDISCIPLINARY COURSE

Harold G. Cassidy

AS I have listened to the proceedings of this Conference, I have asked myself what I could offer you that you might care to take home and use. It seemed to me that because of the wide diversity of your interests the best I could do would be to avoid details and present those methods and philosophy that I have used and tested and that are applicable to almost any rational content. Therefore, let me tell you about a course that I worked out at Yale with Carnegie Foundation support over a period of years: the context of the course, its premises, the criteria for choice of content and methods, and its contents.

Context. I am concerned with non-science and with anti-science students: laymen who may be in charge of important functions in our society in fifteen years or so.

Many of these people are confused and nihilistic, worried about whether there is meaning in life and about who they are (as they put it). I find them, in general, afraid of science and of mathematics, even though they are bright. Moreover, a student with high mathematics aptitude scores may have little mathematical ability. (A careful study by Professor Andrew Patterson showed no correlation between math aptitude tests and freshman chemistry grades—though there was good correlation with verbal aptitude.)

My purpose is to produce citizens who are literate in science. To educate them, I use the medium of physical science—physics and chemistry combined. I want them to be at least desensitized toward science, so they think of scientists neither as devils nor as witch-doctors. I would like these students to be able to read the *Scientific American*, or the *Bulletin of the Atomic Scientists*, or perhaps even the *American Scientist*.

Dr. Cassidy is a professor in the Department of Chemistry at Yale University.

I want them to be aware of the powerful effects on thought that science does exert.

This is the context in which the course in science must be given.

Premises. The premises that underlie the course are *ex post facto* and are derived after the course has been developed through experiment.

This is not a historical approach or a case-study approach. I do not derogate history-of-science courses, but I would use them as advanced courses and let them be intellectual history in part and technological history in part. [1] I am not attracted by the case-study method.

One thing that this course must do is to relate to the student's life. The student is self-centered, like a child, and is usually only beginning to become socially oriented—that is, civilized. This must be taken into account.

The course and its treatment must be authentic. It must "tell it like it is" and be quite open. I have a convention that I propose to the students after they have begun to trust me. I tell them that when I am behind my lecture desk I will be speaking from knowledge and telling them the truth as I see it—and this material may appear on the exams. However, I'll discuss any reasonable subject, and if I am not an expert in it, I'll walk out in front of the desk. This material will not appear on the exams and will not be allowed to take up much time—perhaps the last five minutes of class.

Criteria that govern the content of the course. After several years of struggle I have managed to apply two criteria to whatever I put into the course.

The overruling criterion is that the subjects shall be expected to be important 20 years from now. This presents a rather limited number of topics from which I have chosen a manageable few.

Background material must be *only what is needed* to develop the central themes. This excludes a tremendous amount of conventional and largely repulsive (to them!) physics and chemistry. This criterion has been the most difficult to apply: After all, there are so *many* fascinating things.

Content of the course. What I have said so far may apply to any course whatsoever. It is when these ideas are applied to practice that decisions begin to limit us. My decisions have had to be somewhat arbitrary. People have said, "Well, how do you know that thus-and-such will be important twenty years from now?" To which I have to say that a decision of this kind is always made on inadequate data.

I begin with a single lecture on the intellectual structure of the college to show where, on the "sphere of knowledge and experience," the course is placed. My purpose is to show that it is connected closely to other subjects and that it is in principle related to all other parts of the curriculum. [2]

I then devote two periods to a discussion of perception and meaning. [3]

It is easy to show the students that the information that impinges on the eye (for example) is far more than it can process. Von Békésy [4] has stressed this and has shown how our sensory organs are able to cope with excess information without becoming overloaded. But here, clearly, is a limitation on perception, and I point out and demonstrate with simple psychological tricks how easy it is to lead the students astray; how can I *make* them see or miss things; how I can manipulate them; how easy it is to be fooled. Then I can drive home that an important part of scientific training is learning how to safe-

guard one's self against the subtle duplicities of nature.

This is followed by a talk on meaning. [3] I state the premise that meaning inheres in organized connectedness, and that science is a cumulative development of meaningful knowledge about how the world is. At this time I discuss alienation: If a student withdraws and severs connections with others and with the great body of knowledge and behavior that we call "culture," he quite naturally loses meaning. I usually add, then, for the benefit of the extreme existentialists that, of course, those who believe that life is absurd and without meaning are in an extremely strong position. For if they truly so believe, then it is heresy to look for meaning. Not ever looking for meaning, they will never find any, and so they will be confirmed in their strong position. At this point I can begin to identify, by their behaviors, the unhappy and confused students who will be my concern as we go along.

By this time the students are beginning to wonder what kind of a science course this is. A week or so has passed, and I haven't given them an equation or used any jargon. Worse is to come, for now I do what I think is a key part of the course: I introduce the philosophical framework around which the course is constructed. I mean just this: The course is built upon a conceptual framework with a sound theory of knowledge behind it.

You see, since I really believe in education, and since I believe that what I am teaching is for the whole person of the student and for his whole intellectual life and other experiences, I have to consider the *whole* student. I imagine that most of us do this in an implicit way. But with our present students who are basically ignorant of our culture, and fundamentally a-historical, I find that I have to be explicit—to the point of being corny (in an ancient idiom). They do appreciate it, for they say so.

I introduce this part of the course with Margenau's epistemology. [5] I use his diagrams to show that one may conceive of a world "out there," outside of one's self, which is the object of study. By means that involve operations, one arrives at constructs in the mind. These are invented notions, like space, distance, velocity—which no one has seen—and which are used to gain control of the outside world. These are come to by a process of symbolic transformation: [6] The observed phenomena are converted to symbols that can be manipulated by the rules of logic and algebra. By the process of measurement. numbers can be associated to these symbols and to the rules that connect them.

I usually go somewhat farther to point out that the perceptions belong to what may be called the existential aspect of science, while the constructs belong to the essential. The rules are essential in the sense of being absolute (with a small "a") because we made them so. [3] I promise to return frequently to this point.

I then call attention to the power of science as a way of comprehending the world. I remind them that people like Viktor Frankl [7] (a psychiatrist who survived two concentration camps and speaks from knowledge), Albert Schweitzer [8] (who also speaks from knowledge), and Abraham Maslow [9] confirm in their writing the ancient wisdom that man lives in three dimensions: body, mind, and spirit, or as Frankl puts it, the somatic. the mental, and the spiritual dimensions. I point out to the students that science relies on the somatic dimension for the raw data of perception: through those remarkable transducers, eyes, ears, nose, mouth, and touch that convert the rich texture of the World-Out-There to electrical and chemical impulses that go to our brain. By some method that is not understood, these impulses become known images. The mental dimension of science comprises symbolic transformation and the invention and manipulation of constructs.

But I suggest also that in a deep sense science has a spiritual component. This is what Frankl calls the "will-to-meaning." It is what distinguishes man from the animals. I suggest that science exemplifies one of man's most successful authentically human enterprises: the application of his will-to-meaning in practice.

I find that the students are awakened during the two weeks that this preparation has taken. It is a small price to pay for their beginning to trust and willingness *actually* to listen. At this point I tell them that human beings have struggled for 6,000 years to accumulate the little knowledge we have and to develop tools of reason. That one of the directional arrows in the universe is this: Reason can discover irrationality, but not the other way around. This is why scientists struggle so hard to use reason and why we should never give up one jot of rational thinking. It has been hard to come by.

We now are ready to begin the actual physics and chemistry. Here I use a discovery I made some years ago. Many students who are afraid of mathematics and have forgotten their algebra nevertheless like geometry. Perhaps there is something holistic about the diagrams. For this reason I introduce them to vectors. and since we can do a lot with vectors, it is easy then to slide imperceptibly into algebra through the Pythagorean theorem. Before they know it. they are doing simple algebra without undue pain.

I shall introduce the remaining topics more or less schematically, making special mention only where I have departed from the conventional.

Electricity. I review static charges and currents which the students have had in elementary and secondary school science courses. This is done with quantitative emphasis. Nothing else. (Electrons are assumed.)

Magnetism. The magnetic effect of moving charges leads to a discussion of linear accelerators (ions are assumed) and gets us, after a derivation of centripetal acceleration, to the cyclotron, which can be calculated.

Light. This is the central theme of the course. Geometry leads us into interference phenomena. The Michelson interferometer and its famous use are done in some detail.

Relativity, special theory. This is done in great depth, with algebra. Eventually. after reviewing concepts of energy, we end with $E = mc^2$. This gives a powerful means for showing how in science the genius cuts away appearances and derives earth-shaking conclusions from inspired postulates.

Electromagnetic waves. I use relativity to show how electricity and magnetism are related (students delight in this) and lead into Hertz.

Photoelectric effect. Many students find Einstein's equation a high point. This will be woven into the concept of energy levels, which is a theme that unites atomic, nuclear, and molecular structure.

Wave mechanics. This is approached via a string stretched between immovable points. It is done qualitatively and leads into atomic structure.

Atomic structure and properties. Bohr's atom can be calculated, and after showing how it allowed exact calculation of some hydrogen lines, the anomalies that forced its abandonment and brought on the

wave-treatment follow naturally. This is another paradigm of scientific method.

Nuclear properties and structure. Radioactive decay and the concept of energy levels are dealt with very briefly. Also, dating.

Molecular properties and structure. Polymers, phases are briefly discussed, and then much time is spent in introducing just enough organic chemistry to *prove* the structure of acetic acid and to show (after introducing optical isomerism) how the mechanism of a displacement reaction may be worked out.

At this point about six weeks of the course remain, and I use this time to show how modern concepts in science are affecting our culture. I discuss, and here I give a few useful references:

Probability [10] to show how probabilistic thinking is affecting the Aristotelian either/or attitude—and its dangers.

Cybernetics [11] to show how process-thinking can be handled in terms of inputs, outputs, feedback, and goals.

Particles and fields. This is a discussion of the atomistic [12] versus continuum ideas. What I try to get at here is the changing view of matter and its properties. Namely, that the concept of "primary qualities" *possessed* by matter (position, size, and so forth) are being thought of, at least at the atomic level, as being not possessed, but *latent.* [13] They are evoked in the measurement, as with light. If one uses a wave-finding machi[illegible] one finds waves; a particle-finding [illegible] one finds particles.

I wind up recapitulating the course in terms of manifestations of *variety* (the various particles and properties of matter) and *constraint* (the factors that prevent variety from becoming chaos).

Over a period of many years the course has been well received by the students. They seem to feel that it speaks to their condition. I do not, however, have any quantitative evaluation of the results of the course. I have given some very carefully selected laboratory *experiments,* often in place of a term paper. I give numerous *demonstrations.*

A textbook for this course is now available. [14] The text is constructed on the basis of the philosophy presented in my *Knowledge, Experience and Action,* referred to in Reference 2. Also available is a teacher's manual for the course. [15]

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ASSEMBLY OF THE SCIENCES INTO A SINGLE DISCIPLINE[1]

Edward F. Haskell

PRODUCE men who know why and what they are, with eyes on the future, who are masters and not servants of creation. That, says Szent-Györgyi, is the object of education. [1] That is also the object of unified sciences.

In his famous lecture on "The Two Cultures and the Scientific Revolution," C. P. Snow said the following about our present knowledge explosion: "Nearly everyone will agree that our school education is too specialized. But nearly everyone feels that it is outside the will of man to alter it. . . . All the lessons of our educational history suggest we are only capable of increasing specialization, not decreasing it." Further on, he says: "We seem to be flexible, but we haven't any model of the future before us. In the significant sense, we can't change. And to change is what we have to do." [4] And H. G. Wells anticipated this desperate view with the title of his last and only despairing book: *Mind at the End of its Tether.* [5]

But when mind, or any other aspect of life reaches the end of one tether, it sometimes manages to find another way to make an unexpected leap. And so it seems to be again today: By ascending to a higher level of abstraction and developing a new and different kind of specialization—namely, *assembly* of the parts of science created by the one-field specialists—we probably can combine our powerful one-field specialization's advantages with elimination of their disadvantages. As Seaborg has stated it:

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"The crux of the matter . . . is that the degree of power man has gained through his science and technology must be matched by an equal degree of control—control which demands increasingly greater sophistication as well as constant human orientation." [3]

Until the rise of our Lower Industrial Period, nature effectively controlled the planet Earth. Each species, including pre-Industrial Man, was controlled by other species, by geophysical forces, and especially by the consequences of its own life activities. Together, these natural forces have acted, until now, as safety valves or thermostats; or, generally speaking, as controls. The Lower Industrial knowledge explosion, however, has permitted us to tie down most of these safety valves for a short time; and what is more, to flatter ourselves that this blind behavior is really progress. But the prognosis for this kind of progress is not bright: In terms of Figure 1, it propels mankind's population practically straight up and crashes it against its saturation point. Over half of mankind has already reached the hunger point, and we are reminded that one of nature's most common methods of exerting control is to permit a species to wipe itself out. The alternative is to devise methods of *self*-control.

II. *What are the Conditions for Creating Human Self-Control?*

The first conditions for creating self-control are the products of the information explosion itself; for they are the control-assembler's raw materials. (Many of these parts are directly organizable,

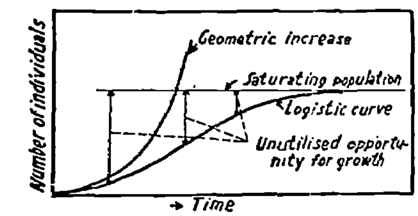


Figure 1. Life Transformation of a closed ecosystem. [2] Courtesy Hafner, New York.

though others have proved to need alteration or adjustment.) This condition exists abundantly and is growing very fast. Existing parts are represented in column 2 of Figure 2. (Please start at the bottom and read upward.) These are the major subassemblies of data produced by the traditional sciences. All of these subassemblies are important; in fact, indispensable. And the most important of them, for assembly of the sciences, is the periodic table of chemical elements, formulated by Dimitri Ivanovich Mendeleev one hundred years ago. This table is the model, and, also one of the components, of our assembly of sciences. Its generalization can probably do for science-as-a-whole what Mendeleev's empirical model did for the physical sciences—namely, mobilize them, and launch them on a course of rapid *organized* growth.

Consider the strategic role of the periodic table: If for example, Marie and Pierre Curie had discovered, *before* this periodic table had emerged, that radium transmutes spontaneously into certain other elements, and these into lead, it would have been simply a very interesting fact. [7] And it would have remained merely a fact until the periodic table did emerge. For only when viewed in the

[1] This is the title of the book whose first volume is here partly summarized (Reference 6).

orderly, meaningful context of this natural classification of the chemical elements could this discovery generate inferences, deductions, hypotheses, predictions, and experimental verifications, and result in chains of further discoveries and practical applications of them. Only within the framework of natural classification could the discovery of radiation have launched what we now call *atomic physics, nuclear physics,* and *particle physics:* or, jointly, the Atomic Age.

The term *natural classification* was coined in 1868 by John Stewart Mill to denotate the following relation: If, he said, an array of natural phenomena were discovered which displayed one regularly changing property, of which many or most of the system's other properties were a function (so that they varied as it does), then by classifying that one property, all these others would be classified naturally, and we would have a natural classification. [8] The next year, 1869, Mendeleev and Lothar Meyer formulated (independently of Mill and of each other) an empirical case of Mill's hypothetical relationship: "The properties of the chemical elements are functions of their atomic weights." This is the periodic law. The periodic table of chemical elements is thus the first empirical member of the set called *Millian Natural Classification.* [6]

Mill's hypothesis and Mendeleev's periodic law jointly constitute what today is called a black box problem. This problem's solution became possible with the rise of cybernetics. For cybernetics teaches that (man-made) cybernetic systems have two basic components: work component and controller. [10] When stated cybernetically, the Millian hypothesis becomes the general form of the periodic law as follows: *The major properties of cybernetic systems are functions of their controllers.* It follows that, if regular variation of the atom's nucleus (by additions of one proton) produces regular variation of its chemical properties (as it does), then the nucleus is the controller and the electron shells are the work component of a cybernetic system. The periodic table of chemical elements is thus a case of Millian and of cybernetic classification, and this black box problem has received a tenable solution. This solution makes the discovery of periodic tables in other disciplines a rationally tenable procedure.

Other researches on Millian natural classification [2,11,12,13,14 and 15] were aided by the work of Gause, Haskell, Moreno, and others, [16] and led to a Symposium on Cooperation and Conflict Among Living Organisms during the centennial celebration of the American Association for the Advancement of Science. At the conclusion of the Symposium, the Council for Unified Research and Education, Inc., was founded. It carries on sustained efforts to find an organizing pattern for all knowledge.

By 1967 the cumulative hierarchy of empirical periodic tables, listed in column 3 of Figure 2, had come into existence, although it is incomplete near the middle as well as at the lower and probably the upper limits. Between the tables of atoms and biopoetic molecules there is a big empty space which, it is predicted, will come one day to be occupied by the periodic table of molecules and the periodic table of geoid systems.

This hierarchy of classifications can be assembled because it consists of nested ecosystems of Habitat-Entity systems. Nonetheless, traditional classifications, such as the plant and animal taxonomic series, are essential components of these periodic tables: They are the lines of descent; of the transformation of each ecosystem into its successors. By themselves, however, taxonomic series cannot be assembled, for isolated organisms neither live nor evolve. They display neither actions nor retroactions; merely inanimate structures. Periodic tables, however, are classifications of cybernetically structured processes. That is why they convey meaning and permit prediction which was not previously possible.

The generally applicable scientific way of seeing and thinking called *cybernetics* and *systems-theory* is restructuring our concepts of the processes traditionally called *phylogeny, ontogeny, evolution,* and *succession;* and it is disclosing their operation in all major fields, physical, biological, and psychosocial. And all these interrelated periodic tables are, at bottom, subassemblies which assemble into an essential part of our celestial ecosystem's *controller, Homo sapiens.*

III. *Overall View of this Control-facilitating Assembly of Sciences*

In the section of Figure 2(2a) on page 11 is an abstract diagram of the natural enactors of Mill's hypothesis: a model of what Klir has defined as the *General System.* [9] This is the template of our assembly of sciences: the guide to our work. Its tentative definition, formulated jointly by H. G. Cassidy and the writer, is: "A system is a space-time region bounded by sharp but not complete breaks of interdependence, the incompleteness of whose breaks are inputs and outputs." [6] This theoretical system purports to be the set, of which all empirical systems are members. Its components are the Habitat (work component) and the Entity (controller). *Habitat* is defined as "All things which affect the Entity or which it affects." (Capitalization throughout this presentation is intended to distinguish terms thus defined from the same terms frequently used to mean different things.) And, *Environment* is defined as "All things which affect the Habitat within the ecosystem, or which it affects." [18] And the arrows of action and retroaction, as also of input and output, conform to these definitions. (The even more abstract terms X and Y are attached to Habitat and Entity in preparation for the theory's geometrization later on.)

In Figure 2, column 1 represents the filling in of the "empty" passages (*Habitat* and *Entity*), one after another. Starting at the bottom and moving upward we substitute, one after another, empirical terms, thus obtaining the System-Hierarchy of Empirical Systems. (It will be noticed, parenthetically, that at the left of this column are two Greek letters, Alpha A and Omega Ω, linked by the system-hierarchy of nested braces. In the coordinate system to be described, Alpha represents the point of maximum entropy or disorganization; Omega, the point of maximum organization known at the time of discussion. These are the limits, and this is the range of systems theory and its geometry. Between them can be ranged all known and all possible natural systems.

The lowest currently known major set of phenomena comprising the empirical Systems-Hierarchy is shown at the bottom of column 1. It consists of unorganized particles. (This is traditionally called a natural Kingdom and is described by a Periodic Table in column 3.) The second entry represents particles organized as atoms. The next Kingdom of the hierarchy emerges when some atoms' electron shells interlock, forming molecules. The next Kingdom emerges when molecules form the simplest geoid system. The next Kingdom emerges when some systems of molecules begin to replicate themselves: biopoetic ecosystems. Those ecosystems whose Entities get their energy from sunlight, thereby enriching their habitats, are called *plant* ecosystems. When, in some

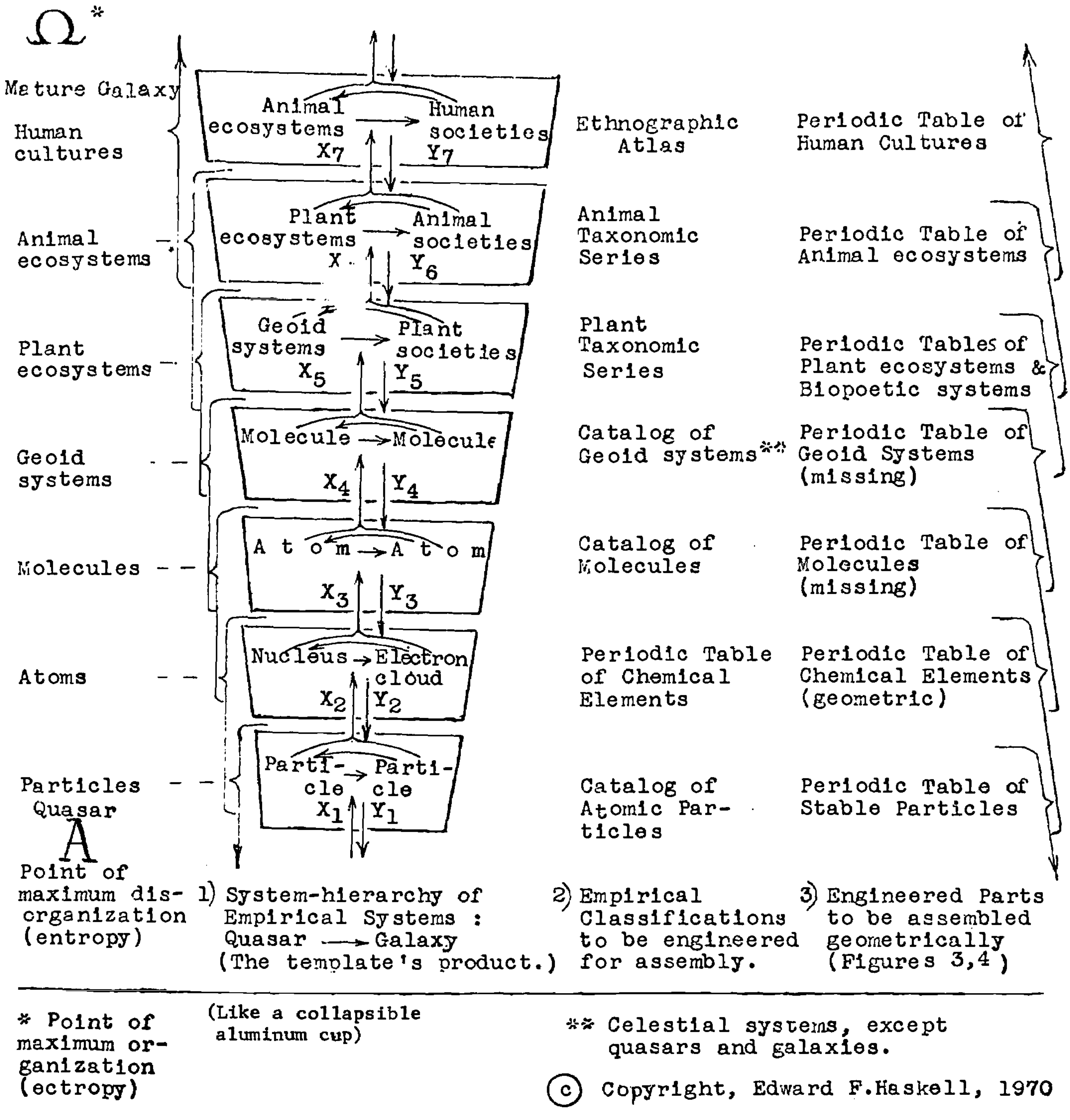


Figure 2. The Cup of Life. Assembly of the Sciences: Method and Product. [6]

of these Entities' descendants, signalloid processes occur, animal ecosystems have emerged. And with the emergence of supra-zoic (higher-than-animal) levels of abstraction, human cultures, have appeared. Each Kingdom of the System-Hierarchy thus consists of all preceding members, plus an emerged property or relation, mutually modified. These are what George Klir has called the S-structures: "System S is specified by the permanent behavior of a given set of elements and a given set of couplings between the elements on one hand, and between the elements and the environment on the other hand (S-structure)." [9]

The Scalar, Quantitative Component. All Millian systems, from atoms to civilizations, appear to be built quantitatively on the following very simple pattern, abstracted by H. G. Cassidy from the several concrete patterns as shown in Figure 3.

The first Period has one Stratum; the

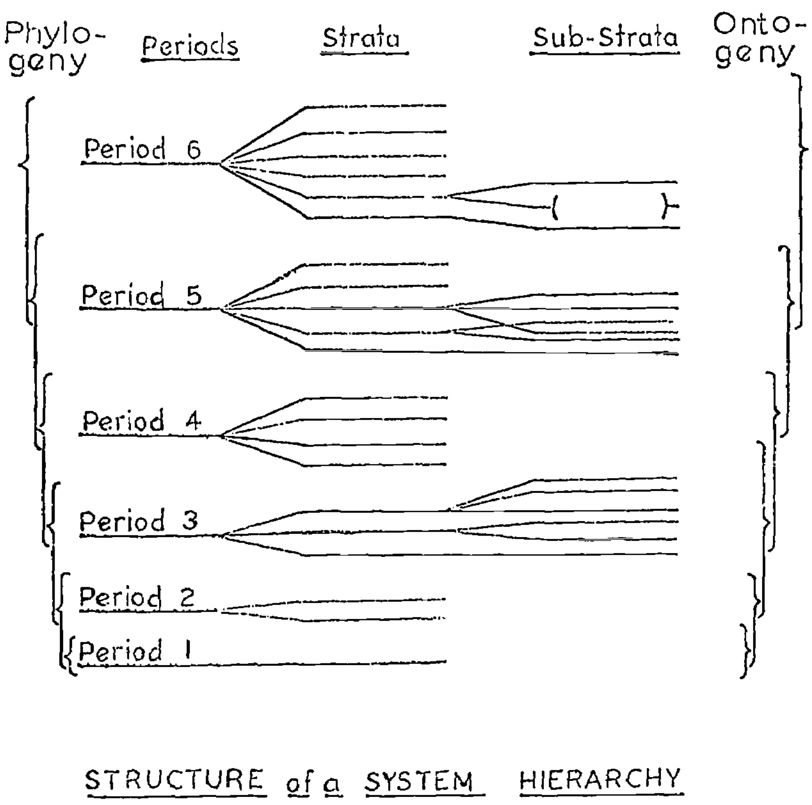


Figure 3. General Structure of Sub-Strata, Strata, and Periods. H. G. Cassidy. [6]

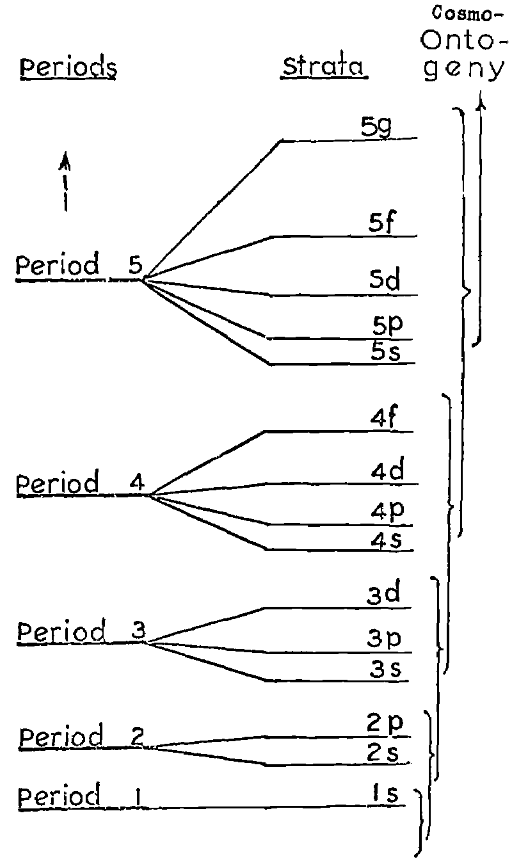
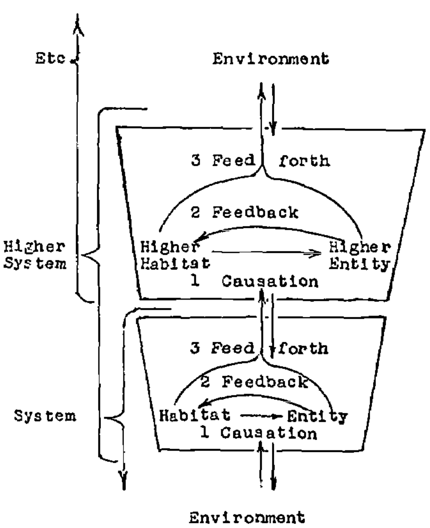


Figure 4. Periodic Table of Chemical Elements: Strata, Periods. [6]



General (Abstract) System-hierarchy

The template for the assembly of empirical systems.

"A System-hierarchy is a hierarchy such, that each member of the hierarchy (except the first) consists of previous members of the hierarchy plus a new entity which the hierarchy has created, mutually modified."
Cassidy, Quine, Haskell, 1964.

Figure 2a. (left) General (abstract) System-hierarchy.

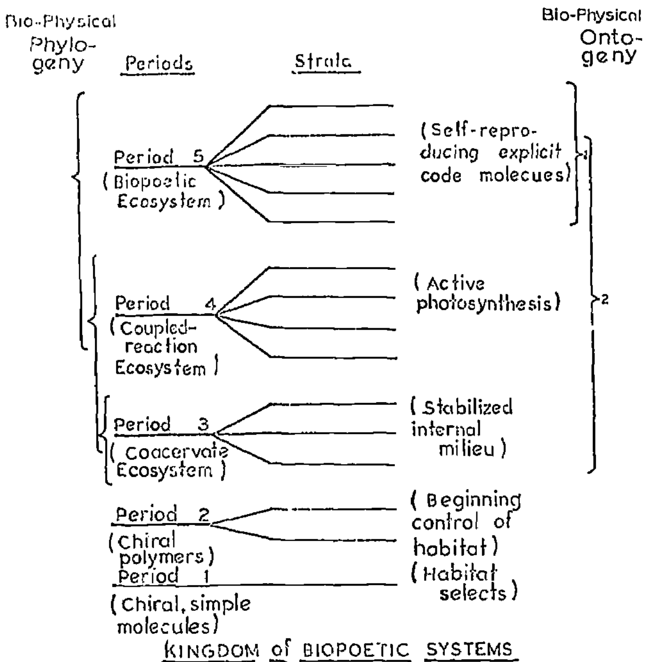
second, two; the third, three; and so forth. The Stratum number is the Period number and also the Sub-Stratum number. Sometimes Sub-Strata overlap or are omitted. Such is the abstract, general structure of all Periodic Tables' Scalar aspect (written with capital letters, to differentiate them from other kinds).

Without going into details, by just noting the general structure, we can observe this uniformity by running through the hierarchy of empirical Periodic tables indicated in column 3 of Figure 2.

In the case of atoms (Figure 4), the Strata in question are both nuclear and peripheral (electron shells); and these are processes, movements characterized by regions of statistical occurrence.

In the case of biopoetic ecosystems (Figure 5), the Strata and Periods are cybernetic processes, chemo-physical ones. In plant ecosystems (Figure 6), the Strata bear the names of structures; but these are cybernetic processes controlled in ways studied by molecular biologists. In animal ecosystems (Figure 7), the Strata and Periods are behavior patterns controlled in series: both genetically and neuro-physiologically. And finally in human cultures (Figure 8), Strata and Periods are genetico-psycho-social.

The Directional or Qualitative Component, the Groups. The qualitative component of all periodic tables is likewise isomorphic throughout. Mendeleev's periodic table of chemical elements (when subsequently completed by the addition of the Zero Group, the so-called inert or noble gases) displays nine Groups. And the reason for this appears now to be cybernetic. This is the totality of the theoretically possible mutual effects of the so-called *coactions* [16,20] which this system's work component X (the electron shells) and controller Y (the nucleus) can have upon each other. Each component can increase the other's capacity to participate in the emergence or mainte-



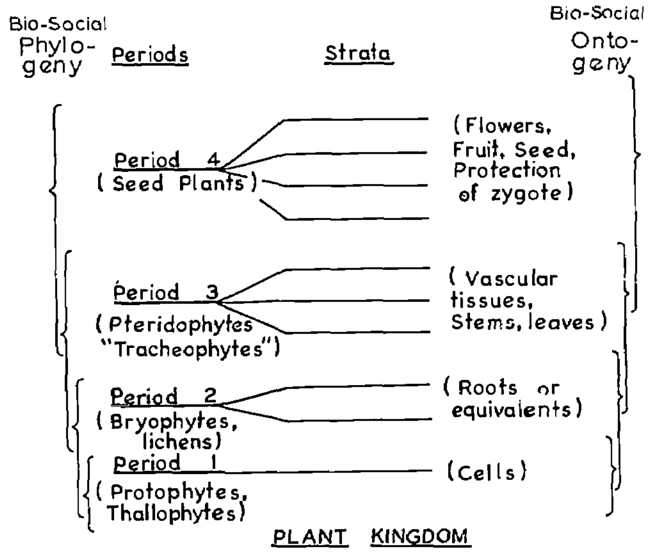
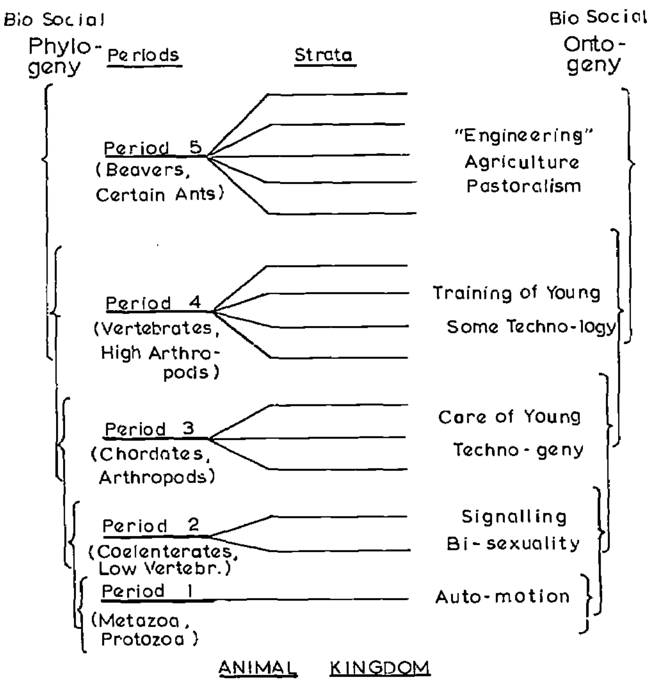


Figure 5. (left) Periodic Tables of Biopoetic Ecosystems: Strata, Periods. H. G. Cassidy. [6]

Figure 6. (above) Periodic Table of Plant Ecosystems: Strata, Periods. [6]



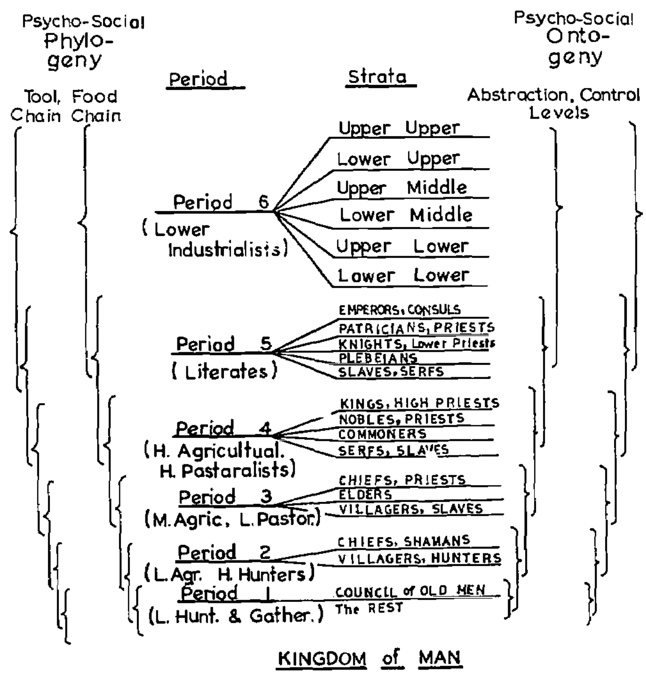


Figure 7. Periodic Table of Animal Ecosystems: Strata, Periods. [6]

Figure 8. Periodic Table of Human Cultures: Strata, Periods. [6]

nance of higher members of the Systems-hierarchy, can decrease this capacity, or can leave it unaffected. If increase is represented by a plus sign (+), decrease by minus (−), and the unaltered capacity by zero (0), then the theoretical totality of coactions is obtained by cross-tabulating these signs for X and Y: which, of course, yields nine coactions or Groups. [16,20] This cross-table is immediately seen to correspond to the nine sets of directions of a traditional coordinate system's radius vector, as in Figure 9.

Because we are organisms, the meaning of the Groups becomes clearest to us if we consider the biological regions of the emerging general scientific map. I have therefore chosen biological rather than chemical terms for this initial presentation. The familiar concepts *Symbiosis*, *Predation*, and *Parasitism* are here defined both geometrically and cybernetically: geometrically as axes and quadrants in a coordinate system; cybernetically as rela-

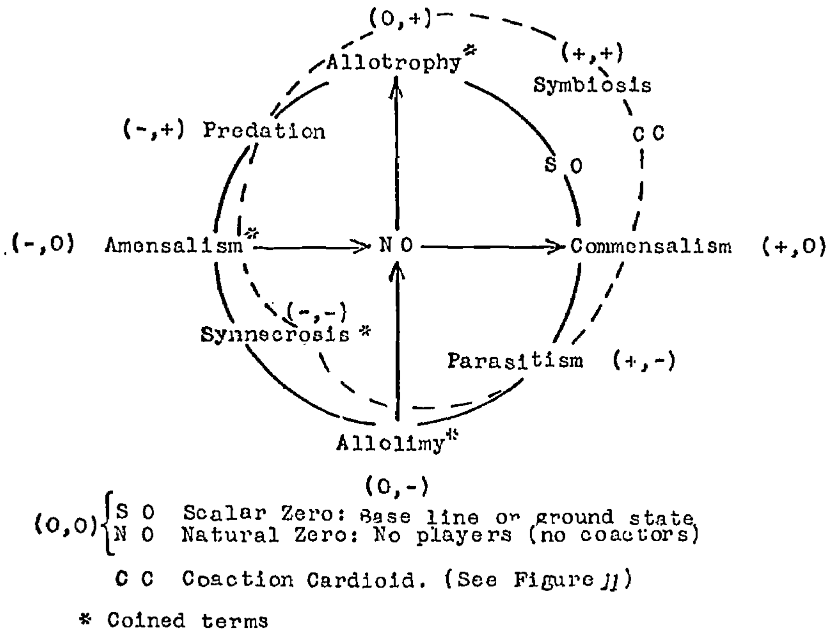


Figure 9. The Periodic Table's Groups. Obtained by Cross-Tabulation of the System's Cybernetic Components: X Work Component, Y Controller. [16,21]

tions between the ecosystem's work component or Habitat X and its controller or Entity Y. (Look again, please, at Figure 2a.) Less familiar terms—such as *Commensalism, Neutrality,* and *Synnecrosis*—are hereby clarified. And missing terms (terms whose meaning is defined geometrically, but for which no traditional terms seem to exist)—*Amensalism, Allotrophy,* and *Allolimy*—are conceptualized and invented. [20] Only after the familiar empirical coactions had been dis-interpreted—that is to say, formulated abstractly as here—was the unfamiliar ones' absence noticed and the absentees named, and then discovered empirically. [6,20]

Experience over the past decades shows that the kind of prediction and control which Mendeleev's periodic table conferred upon physical scientists is hereby extended to the psycho-socio-politico-economic domain. Such is the general nature of our map's Groups; of its directional or qualitative component.

IV. *Assembly of the Scalar and Directional Components of All Periodic Tables: Unified Science*

Assembly of these components results in the Periodic Coordinate System, Figure 10.

Its structure is as follows: Its limits are A and Ω, the points of maximum disorganization and maximum organization. Naturally, therefore, two of its coordinate axes (interpreted as the work component and controller of the General System) are directed toward Omega and labeled $X\Omega$ and $Y\Omega$; while the other two, X_A and Y_A are directed *inward* toward Alpha. Buildup of the System-hierarchy extends outward in the region of predominantly and wholly positive coactions. Breakdown and devolution are shown in the opposite region. Yet both are represented by positive numbers.

Negative numbers do not occur in this coordinate system. For when a natural system breaks down (say, when an animal dies), it does not become a negative animal. It disintegrates into successor systems lower in the hierarchy: tissues, cells, molecules, atoms, particles. When a molecule breaks down, it becomes not a negative molecule, but successor systems lower in the hierarchy: atoms, particles. (Only the System-hierarchy's lowest Entities, particles, have anti-entities which must be represented by anti-numbers. And at that point the Periodic coordinate system undergoes a drastic change. [6] But with this exception, which space does not permit us to discuss, all known natural phenomena are positive entities. All coordinates in this part of the Periodic coordinate system are therefore positive and belong to the positive portion of the Real number system.

To represent this state of affairs, a series of concentric circles has been drawn in Figure 10 representing the empirical hierarchy of components, column 1 in Figure 2. In Figure 10 just two Scalar Zero (SO) circles are shown, representing two natural Kingdoms or Major Periods. But in the complete figure, every Sub-Stratum, Stratum, and Period of the whole System Hierarchy would be represented as well.

These SO circles represent these Entities' *nul* derivatives, their derivatives of position, relative to which their derivatives of change—whether buildup into higher positive, or breakdown into lower positive Entities—can be represented.

When a new concept emerges in which natural classification in the sciences and natural law in the humanities are central, what has happened? Szent-Györgyi foresaw it when he said, "There are no Two Cultures." [1] And C. P. Snow, in his revised lecture "The Two Cultures—And A Second Look," anticipated the rise of a Third Culture, combining the essentials of the previous two. [21] Does not this occurrence end "That Parting of the Ways"; the fatal separation of Christendom's Literate and Scientific cultures in the 15th and 16th centuries? [22] And is not that a leap?

V. *Inter-Disciplinary Education, the Basis of Control*

Pupils are taught by teachers, and teachers are taught in colleges. But college professors are taught in departments each with its own concept-system; its own area of competence and authority; its own socioeconomic hierarchy and chairman. And these departments are organized—for purposes (as Sir Walter Moberly affirms) of fund raising and housekeeping [23]—in a confederacy which Clark Kerr has aptly called the *multiversity.* [24]

Since each department evolves autonomously, it is unconscious of the communications barriers it builds against the others, but the consequences which we suffer, are these: On one hand, "An incredible explosion of knowledge; a tremendous increase of the power and influence that human beings can exert over their environment and their fellow men." [3] And on the other hand the *preclusion by this centrifugal structure* of developing "The crux of the matter . . . an equal

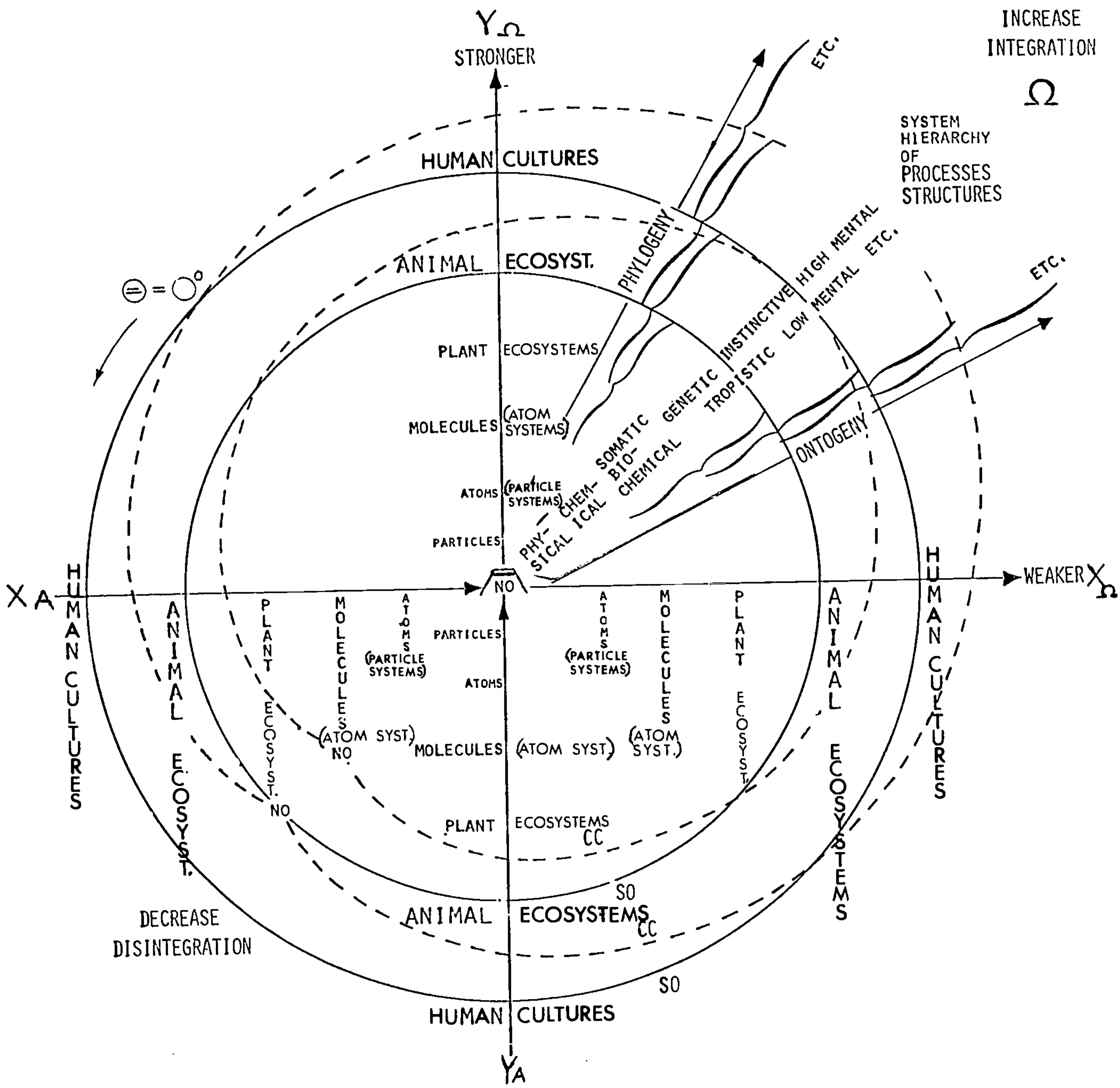


Figure 10. The Periodic Co-ordinate System. [6]

degree of control." [3] To control the knowledge explosion, it must be understood. Yet it can be understood only in terms of the element that has been filtered out: Namely a working grasp of the structures which the departments' subjects have in common. What else than this has put mind at the end of its tether?

The multiversity's explosion has such momentum that it just gobbles up, or stifles, the piecemeal syntheses with which of us naturally have been trying to confront it. Over and over, during this four-day Conference on Interdisciplinary Education, we have heard how individual interdisciplinary courses tend to get incorporated into some existing department, or to wither away for lack of career prospects, credits, and degrees. Over and over we have heard how a crusader has emerged and rallied an active interdisciplinary faculty group which worked until, worn out by the system's centrifugal inertia, it faded away.

How, then, can interdisciplinary education come about? There is a way, and its overall nature was outlined a few years ago by Jerome Wiesner in a televised discussion with C. P. Snow which went roughly as follows. (I quote from my notes, but not verbatim.) The kind of change we need, said Wiesner, probably cannot occur piecemeal. The forces of tradition are strong, and individual changes tend to get changed back. It has to happen all at once. [25]

This means, it seems to me, a leap. This leap, however, becomes possible only after extensive analysis of the structures which natural kingdoms of the universe, and therefore science departments, have in common; after extensive synthesis thereof, couched in mutually understandable constructs; and after an adequate period of testing, revision, and development. This preparation, C.U.R.E. has been quietly carrying out over the past 21 years. [17] Its results are set forth in a still unpublished book, one volume of which is here before me: a book whose overall title I have borrowed for this talk: *Assembly of the Sciences—Into a Single Discipline.* [6] For when, and only when, these theoretical prerequisites have been carried out, then does it become possible for the kind of change we need to happen all at once in practice.

The operation by which it can occur in practice requires, first of all, establishment of an Interdisciplinary Center. Such a center can either be set up within the ongoing college or multiversity, which it is in time to restructure; or as an autonomous nucleus which is itself to grow into a university; or as a sort of combination of the two procedures.

In the first case, the Interdisciplinary Center establishes a Seminar which is attended by one or more interested members of each science department: physical, biological, and psycho-social.

In the course of this seminar unclear or dubious formulations will be challenged and thrashed out, will be destroyed, vindicated, or reformulated. If, in the process, this model of synthesis proves unable to outlast the resistance and demonstrate or acquire correctness, it will be screened out, and the multiversity will continue to explode educationally and, perhaps, socially as well. But if it overcomes the various kinds of opposition and, in the process, incorporates significant personalities into a cooperating team of synthesists, then we may .. ..ct the following development: Courses in every science department will be restructured and textbooks rewritten in mutually understandable constructs and notation. Hereby they will come to support and develop each other far more effectively than their unassemblable competitors do or can, tending not only to resist the forces of explosion but to transform them into implosion. In order to organize the product of the multiversity, the structure of the university will hereby be reversed.

This result, however, may also be initiated in a different way:

The chances that all, or even most, of the science departments of any given multiversity will wish to participate in this difficult kind of seminar are not very high. (The University of Chicago's Inter-Divisional Committee itself was not complete, and had to be informally supplemented in the physical sciences—namely, by Harold G. Cassidy of Yale.) We thus should not be surprised if the Interdisciplinary Center at any given college has to recruit synthetically oriented scientists from elsewhere in the nation, as C.U.R.E. did from the start. This makes the following two courses possible: The preferable one is, that the Center's scientists are accepted into the local institutions' science departments and assist them to transform their development. But, failing this, the Center would have not only to recruit and train synthetically oriented scientists wherever they may be found, but also to organize courses of instruction thereby becoming, in effect, a university.

The forces of change are clearly all about us. On one hand, student-faculty riots around the world driven, by the knowledge explosion, toward catastrophe. On the other hand, interdisciplinary conferences, courses and centers like ours around the world are organizing these forces toward a higher Period. To stay with the status quo is to intensify disintegration. But for us to become, under God, masters and not servants of creation, control-building operations must be launched and intensified at once, with all our energy.

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DISCUSSIONS

The following material has been prepared from transcribed tape recordings of the discussions in small-group sessions. Comments made by staff members of the National Science Foundation and other institutions represent personal views or views expressed to bring out discussion and do not represent the official position of the participants' agencies. Participants' full names appear in the roster on page 29.

What Is Our Goal?

KORMONDY Let's set forth some of the questions that we ought to answer before this conference is over. For example: Where do we go from here? Do we encourage people toward interdisciplinary studies?

FENNER And what about action? What kind of action is recommended?

HASKELL Some specific recommendations should be made, and these should be stated with an eye toward what kind of response they will evoke.

FIASCA Most of us here are really talking to ourselves, for we are already oriented toward interdisciplinary science. Some of us will have to think as a devil's advocate and argue strongly for continuation of teaching the separate disciplines. The most significant question to ask is: How do you move? How does the Foundation move, from the level of people talking among themselves to the level where people really do something? There are groups presently engaged in action programs, but they already have their hands full and can't think of taking on anything else. The various commissions have this problem, too. They listen to all kinds of interesting schemes, but *"How do you get the troops moving?"*

PARSEGIAN Another important question is: What are the obstacles to interdisciplinary plans? For instance, if you are talking about high school programs, what are the problems of entering college from any improved program we might have in science? Even the name, interdisciplinary science, is an obstacle. Some call these interdisciplinary courses Honors Physical Science. This is supposed to give a bit of status. My own course is not called physics—it's called physical science. The second-year part of the course is called life science.

A Struggle with Definitions

LIVERMORE As we struggle with definitions, let's distinguish between what we might call a nondisciplinary approach and an interdisciplinary approach. The "inter" is important. In an interdiscipinary approach, one is looking for the cross connection—the concept that Dr. Szent-Györgyi was discussing in his speech. In a nondisciplinary approach, one may find just a single unit, with no obvious connections.

MOLYNEAUX I got the idea that Szent-Györgyi was not talking about interdisciplinary *science*, but interdisciplinary *education*, which means an entirely different kind of education. You don't have a mathematics course, or 20 minutes of mathematics per day. You get the mathematics that you, as an individual need to solve the problem that is apparent for you.

FENNER Distinctions between interdisciplinary, multidisciplinary, nondisciplinary are largely of our own making. The breaking up of the sciences into chemistry, physics, and so on, has resulted in problems.

PARSEGIAN Nondisciplinary, interdisciplinary, and multidisciplinary all have limitations with respect to what we are trying to do. An integration of the sciences may be a little better, aiming toward the science of natural processes. But again—the question is how to approach it.

HASKELL There are principles which extend all through natural phenomena. Through the concept of stratification, one can get at some of the principles that are universal in nature. Stratification exists throughout the universe and can be physical, biological, social, even psychological.

PARSEGIAN Mike Fiasca and I were at the conference in Bulgaria on interdisciplinary teaching. Invariably the approach there seemed to be this: When people in various disciplines talk about a theme of interdisciplinary education, or whatever type of education each one is interested in, there always seems to be an interest in *one* question; namely: "How much of my discipline can I squeeze into this thing called interdisciplinary?" When one man talks chemistry, another geology, another this, and another that, each delights in proposing that a certain main theme from this discipline is important to incorporate, because, of course, *this* we must have. But they seem to shut their ears when it comes to other men's points of view.

Thus we have special interests pushing into this package that is supposed to be interdisciplinary or multidisciplinary, but without sufficient awareness or interest of how their treasure ties in with the other fellow's main interest. Our biggest stumbling block right now is how do we get the thing that I, as a physicist, want to put in, joined with the key aspects of geology, chemistry, biology, this or that, in a manner that shows the underlying theme and the substance content, rather than that I squeeze into it as much physics as I can or as much chemistry, and so on?

MOLYNEAUX Are we going to get this melding if we think just of science? This is really the philosophy of the whole school, and all subjects have to come into the concept building. You cannot divorce mathematics from this mix. Mathematics is a tool a child uses to solve a problem in science or anything else. He also has to use language arts; he has to use social studies. Somehow, we have to determine the concepts important for a child to know and teach him to think for himself and how to solve his problems. But we must also have teachers with a philosophy—teachers who deter-

mine what the concepts are going to be and who develop the body of knowledge needed to get across this philosophy.

FIASCA Should we look for a single unifying science program? The answer to that is "No." We should look for diversities. There are numerous viable ways to unify the disciplines and bring them together, at least to accommodate the teacher's preferences, interests, geographical locations, and all the other variables. It is a mistake to move on one vehicle. For example, there is evidence that teachers who become familiar with one of the new curriculum programs, after teaching it two or three years, lose enthusiasm. A teacher sustains excitement only through inventions of his own.

Taking Off From, or Holding To, Structure

BURKMAN What do we mean by interdisciplinary science? What kind of teaching represents interdisciplinary teaching?

CALANDRA Historically, interdisciplinary sciences have been in existence for quite a while; biochemistry and physical chemistry date back to the 19th century. In fact it is difficult to name any discipline that has not been related to some other discipline. The basic question that we face here is the extent to which the interdisciplinary format has pedagogic value. A negative case can be made for some situations, and a positive one for others. For example, it would not seem wise to teach either biology or chemistry in high school by starting with biochemistry. The study of biochemistry is probably most valuable when the students have some sophistication in the disciplines of biology and chemistry.

The danger of too early an interdisciplinary approach is that we tend to lose sight of the fact that the disciplines are structures made up of intellectual modules. Thus, biochemistry is made up of basic ideas in biology, such as cell theory, and basic ideas in chemistry, such as the kinetic molecular theory. These basic ideas are modules with which the interdisciplinary structure of biochemistry is built. If the student is unfamiliar with these modules, it will greatly limit his ability to do interdisciplinary work. That this actually happens at the junior and senior high school levels is seen in many of the newer curricula. The dangers are highlighted in the course known as PSSC (from the Physical Science Study Commission). Here, as indicated by the title, the original intent was to prepare a physical sciences course. What appears to have happened is that the workers in this field found the integration of the physical sciences at that level impractical and went back in the direction of physics, with very uneven results. Similarly, the blue version of the Biological Sciences Curriculum Study program presents serious difficulties for students not grounded in chemistry and biology.

BASSETT I agree with everything Mr. Calandra has said in respect to the professor, but I disagree with everything he has said with respect to the subject. In observations of children, I am struck by a characteristic which they have at age five to ten. This priceless characteristic, which is progressively killed, is the ability to wonder. And wonder is inversely proportional to the amount of structure. I agree with Szent-Györgyi that, particularly in the tender years, there should not be structure. Science teaching should be completely interdisciplinary, and it should be aroused by wonder. The wonder, in turn, is aroused by observation. Children perceive what they discover and what they are guided into subtly, not with a bludgeon. In all of the elementary programs, the words chemistry, physics, and biology do not even come up. The programs are merely called science for the elementary student.

A corollary of that is in Alfred North Whitehead's *Classification of the Ages of Learning*. He classified the first stage, which is roughly parallel with our elementary school, as a romantic age. The second stage, which corresponds roughly with our secondary schools, is the age of precision. And the third stage, he classifies as the age of creativity.

However, we do come to the question of "When do you begin to specialize?" In New York State, with our rigidly structured educational system, we begin specialization in junior high school and particularly in the senior high schools, where we immediately go into professional education. We have biology in the tenth year, chemistry in the eleventh, and physics in the twelfth. This supposedly is the age of precision. My question is this: Is it necessary to become disciplinary at the secondary school level—particularly since young people today don't have to decide what they are going to do until about their second year of college? I don't think we need to specialize in chemistry and physics and biology in the secondary schools. But there has to be science; and so, by definition, it has to be disciplinary science. Now, how are you going to teach it?

DROZIN In my opinion, integration, or what is now called integrated subject matter, can be achieved in three ways—one: integration from above, in form of a philosophy of science or history of science. In this case, we use the vocabulary provided by philosophy in which the terminology of the particular subjects is dissolved. This approach also includes the sociology of science and science and technology, where we are concerned with the effect of science on society directly and through technology. Without technology, we cannot see how our society is going to be developed.

The second approach is integration from below. An example is a course taught together by several teachers, each keeping the terminology of his own discipline, and organized into chapters, perhaps with no connections between them. It is like using the CGS and MKS systems in the same problem. If you mix them together, nothing is in place. The same thing is true by mixing physics and chemistry. You destroy the structure of both.

The third approach, and the one which I favor, is provided by cybernetics. Cybernetics offers a vocabulary equally well suited to practically every science and even to the humanities. I speak about cybernetic vocabulary not as scientific terminology, but as a metalanguage in which one can express other languages.

My students will not be lost in our society if, after studying cybernetic vocabulary and method, they can come to a research lab and ask scientists there: "What is your system? What are your inputs and outputs? What are your input and output channels? What model did you create from your data? How did you verify the correctness of this model?"

KRUPSAW Do you want to teach science in the disciplines to get at the real base of each particular subject, or do you want to keep the romance of it —which depends entirely upon the age, the educational background, and the ultimate aims of your students? Students have to have their personal needs met in the courses that are offered. We are deal-

ing with some young people who know what they want—to become chemists, perhaps—and they are not interested in what we are calling interdisciplinary science. They are well motivated and want to go into one subject very thoroughly. Others, unfortunately the majority, are very low in mathematical ability and don't know what they want to do. Some of the interdisciplinary courses that bring the wonder of the world into the context of the student's own observation, even at a college level, can stimulate an interest in the student. With some of our interdisciplinary type courses, or some different kind of learning situation, you can reach many more youngsters than you can if you start viewing a rigorous body of facts. There certainly is a place in science teaching for all kinds of courses.

BURKMAN While we are speaking of structure, I want to put in a plea for another thought that should run through our discussions: There is now a fair amount of evidence to the effect that the psychological structure of children is not the same as the structure of the subject. To teach a given thing, a new principle that you want the child to know, whatever structure you use to lead up to it is likely to be wrong for a fair number of students.

Perhaps the structure we have, whatever that is, is an artificial one, because it is the structure of the subject which may or may not be the structure to fit the psychological structure of the student.

BASSETT It is entirely possible that one structure will work with one class, and another structure with the class across the hall.

BURKMAN Therefore, perhaps the best way would be to make available the possibility of creating all kinds of structure out of the same basic set of elements.

DROZIN What you said would work well in terms of a single student, but if you have 30 students in your class, and each has a different background, how are you going to give exactly the needed amount of needed information to each of them?

BURKMAN Obviously, that is the kind of question that cannot be answered today, but I can propose a hypothesis: Don't be limited by the capabilities of the human mind. All 30 students should have a chance to determine their own structure. To keep an individualized classroom under control is a real problem. The human mind is probably not capable of processing all of the information on 30 students working individually, and perhaps this is where a computer would be a help. I'm not thinking here of the computer used in a direct tutorial way, but rather as a procurer of information and guider of the student that provides the teacher or student possible next steps among the many possibilities. In this approach instructional materials would take the form of "bits" of texts, etc., rather than complete courses. With the help of the computer and teacher the student would put together his own course structure geared to his own abilities and interests.

CALANDRA Another thing that bothers me about the interdisciplinary approach in spite of its value in some instances is that some of its proponents often are not sensitive to the fact that the disciplines have a structured intellectual content; and they tend to be enthusiastic not only about interdisciplinary approaches but also about nondisciplinary approaches with a great emphasis on creativity, innovation, etc. These glamor words, in our times, are unfortunately sometimes escape mechanisms for unwillingness to cope with the fundamentals of the disciplines themselves.

It is, of course, true that interdisciplinary approaches are also favored by highly competent educators whose enthusiasms arise from their deep insights into both subject matter and pedagogy, but these individuals are rare and their influence could lead to the recommendation of a general direction for all teachers, of patterns of instruction whose viability depends on exceptionally talented and well-trained teachers and students. At this time in history, such recommendations should be made on a very limited basis in experimental situations. None of these remarks should be construed to negate the values of interdisciplinary overtones in the teaching of disciplines, but they should not be presented in a way that belittles the values of the disciplines themselves.

CASSIDY I'd like to use a different way of approaching innovation. I'd like to think in terms of variety and constraint rather than of innovation. What we have to do (at least this is my approach at the college level) is to maintain variety in approaches and subject matter, with constraint. The constraint is the application of reason and discrimination, which is the essence of education. The discrimination between what's good and what isn't. This takes care of the perfection idea, because variety makes innovation possible. Constraint makes possible these maintenances of quality. I think the interplay of the two of them is what you want to get at.

CARLETON In this discussion, and in many others I have heard over the years, our observations seem to focus on what in science, or what part of science, or science in what form and in what package should be presented? Rather than that, we should raise the question: What from the whole vast storehouse is germane and important in the education of kids, at their level, and in their environment, and within their experiences or abilities? Ninety-five percent of all the kids who are in grade six now will never end up earning a dollar through the scientific endeavor, or even technological endeavor—unless you extend this to being a garage mechanic or truck driver, etc.

It seems to me we cannot overdo the unending pursuit of an answer to the question: From what in science by way of facts, generalizations, conceptual schemes, or whatever I personally like, can I get the most meaning in terms of big ideas, broad ramifications, integrative ideas, in science? To me, this means a nondiscipline-oriented treatment through 12 years at least.

First, you try to identify the goals, purposes, and the reason for science in the education of children. And then you pull into the program whatever from chemistry, physics, biology, earth and space areas is most important.

BURKMAN I like Szent-Györgyi's idea of teaching science so that people won't be bored. Twenty years from now, society is going to be quite different. One thing we must try to do is to prepare for possible employment of leisure time—to read about and study science as a sort of avocation. What does a child who will later be an intelligent consumer of science need? He needs facts; he needs principles; and he needs some notion of what science is about. He won't get these things if you narrow the field of science very much. The sounder the picture of science he gets, the better science consumer he is going to be.

CASSIDY This is where the cybernetic approach is tremendously valuable. Via cybernetics, you are teaching the inner nature of process seen. What you are interested in is that processes that are basic don't change. One can comprehend increasingly larger systems as one's comprehension grows.

BURKMAN On a lower level and different organization base, there is similarity with the elementary science project of the American Association for the Advancement of Science. The AAAS said, let's not center on the specific content, that gets fragmented; let's concentrate on process. The processes are different from cybernetics—they define them as psychological skills—but this certainly sets an example and provides a possibility for interdisciplinary science, organized with process as the vehicle of the content as opposed to the other way around.

KRUPSAW Someone raised a very good question when he asked, "What are we looking for when we are talking about interdisciplinary science?" It's not a panacea. Are we trying to reach the segment of student populations that do not have a specific interest in science or a specific goal in scientific endeavor? Are we trying to get them to imbibe science to the greatest possible extent and possibly enjoy it a little so there will be less anti-science? Can interdisciplinary science do this? Can it do it better than an elementary or survey course in one specific discipline?

BURKMAN Some suggestions have been made here. In the cybernetic approach, they're talking about providing intellectual tools that are useful not only in what we call roughly science, but are intellectual tools useful in a broader context. What Carleton is talking about is having a better perception of big ideas or content in a different way than the contents that have been developed. He is urging us not to stay in the rigid boundaries of content physics, chemistry, and what have you and why. Another very important point for anyone who sets out to do an interdisciplinary science course, whether it is for one group of students in college or for two million students in the country, is that you can anticipate trouble from two points. One, acceptance is going to be a problem. Such a course will have many, many critics. Two, the "system" is going to be very difficult to overcome.

CASSIDY What we are after here is: Why teach an interdisciplinary course? Is there something that it has that others don't have? One thing that such a course can have as a criterion in the choice of subject matter is: Will that be important to these people ten years from now? I have no crystal ball. On the other hand, it is perfectly clear that there are some things which are going to be important 20 years from now because you see that they are already being important. One of them is cybernetics, one of them is probability, one of them is relativity, another is symmetry relations. These are highly abstract as stated that way, but it seems to me that these are the things that 20 years from now are still going to be important.

Sights on Quality Teaching

SCHUBERT We feel uncomfortable teaching what we do not really know. Nor should we teach that which we do not know. If you are committed to the notion that there is something worthwhile about the philosophy of an interdisciplinary science program, if you like the philosophy, then how do you go about teaching it? Obviously, you can't be fully expert in everything you do. On the high school level, a teacher can know more, and should know more, than the students. If the teacher is committed to the notion of interdisciplinary science and is committed to the second notion that somehow or other he must do something about it, then he can teach an interdisciplinary science course with competence, even though he knows the subject only pretty well.

WOOD What difference is there in what we are talking about now and what we had when we had general science?

CASSIDY There was no depth to the old general science, because there wasn't an effort to develop a philosophical concept of it, at showing implications, or pointing out relationships to the rest of the curriculum.

WOOD But one of the reasons there wasn't, at least in our experience, was that a biologist or a physicist or a chemist taught it, and the chances were pretty slim for the course.

Moreover, do we have the kind of people we are talking about to teach interdisciplinary science? Somebody has to teach how to teach interdisciplinary science. If we don't do it at the college level, somebody else is going to have to teach the teacher how to design a course to be taught at the high school level. Can you imagine anybody taking the 20 courses he would need to cover the science required?

CARLETON But there certainly is the need for the teacher having some understanding of what science is and what it's about.

DITTMER A teacher who has been educated to any level of specialization should have a pretty good general idea as to what science is all about. He needs that to teach. If he doesn't understand the general basic sciences, how can he show interrelationships?

CARLETON I don't think he is particularly interested in showing these relationships. However, there are people who are capable of bridging the gap. There needs to be some provision made to give them an opportunity to use their abilities and still not have this be professional suicide.

SCHUBERT I think that we are talking about two different things: college and high school level. High school teachers will teach three different subjects—physics, chemistry, and biology. We lose sight of the fact that at the high school level, the depth of understanding is not what we expect at the college level. It wouldn't be feasible to train a high school teacher to teach a multidisciplinary course: They expect to do that anyway.

The interdisciplinary course in college is a touchier subject, for all kinds of political reasons. If a teacher had a year in each discipline, say, and some specialization in something, then there is a chance he would feel comfortable teaching an interdisciplinary course in the high school level.

Many of us have said, "If you don't have a qualified physics teacher, you shouldn't give a course in physics." But schools do, anyway. If you have a high school teacher with, say, 50 credits distributed across the board, you don't need a special college course in interdisciplinary science. What you do need are the courses in science and a sort of attempt at motivation of the teacher.

Of course, it is much better to make a man take 40 hours of physics so that he can teach physics, but that's not the

question we have to ask ourselves. What we need to know is: Is it better for the student, if we teach him physics or if we teach him interdisciplinary science?

How Do We Get the Troops Moving?

FENNER Without doubt, teaching, as we know it, is one of the most inefficient processes imaginable. It is hopelessly redundant—and without the saving grace of any kind of structure that seems to go to the core of the matter. The real problem is one of communication.

What we should aim at is how to reach the teacher. However, in order to reach the teacher, one must go through a kind of filter—school boards, principals, and right on down the line. To get to the teachers also means to get to the new ones who are coming up—and that means reaching 50 college teacher training programs. We can spew out a lot of lofty ideals, and a lot of good thinking can go into this, but where's the difference between theory and practice? It is impractical to say, "Here is a good idea." We can take a historical approach or any other approach to get across a whole body of information, but students are mobile. They don't stay at any one school for 12 years. And there is zero interchangeability from one part of one city or state to another city or state.

DITTMER I think we can expect innovation in the high schools. The junior high schools are important and some excellent programs are developing. However, the problem of high school drop-outs and lack of motivation will have to accelerate changes in the high schools. I would predict that we are likely to see greater emphasis in the high schools toward vocational studies. We must devise some new approach to get students of the ninth and tenth grades into science courses and to hold them there.

FIASCA To get the troops moving, we need evidence that integrated science is a better way. What evidence do we have that the integrated approach is superior to a separate discipline presentation? Not much as yet. The Portland School District with the National Science Foundation funding is experimenting with an interdisciplinary biology, chemistry, physics sequence. Public school teachers cooperating with university scholars have a chance to try out some of their own ideas.

We have some preliminary evidence to report. We have found that when students start a three-year sequence they are more likely to stay another year than if they enroll in a single discipline course of study. This is true even of the average and poorer students.

DITTMER I believe that the time has come when the high schools must stop mimicking the college program. There are new teaching techniques now—the kind of things that can be put into a course in addition to the usual materials. The bright student doesn't have to be cheated. He can move through a total integration of concepts and facts in one year where the average student takes three years. Some of the experiments in the junior high program which are concerned with biological phenomena need chemistry. These kinds of needs must be brought together in the whole program, and I just don't buy the idea that the structure doesn't make a difference, or that what we have been doing is the best we can do.

KARPLUS What, then, should be the focus of teacher-preparation activities? Suppose we can arrange the supporting background, the educational planning that will permit a new dimension, or a new horizon to be attained in education? We did not completely agree on the nature of this new horizon. Someone used the term nondisciplinary, which suggests a project orientation, rather than a disciplinary focus. That is one problem. Another is the interdisciplinary scope. This can be within some sciences, all sciences, or even broader, where either the sciences and the humanities are together, or even the natural sciences, social sciences, and humanities, all melded into a still grander, interdisciplinary approach. Where is the focus on educational activities?

FIASCA Teacher preparation always looms larger as a problem of teaching interdisciplinary courses, but I'd like to put forth the notion that if the courses were available—and if they were being taught—it is possible that the teacher training programs would accommodate to the curriculum.

WEITZ Another problem in teacher preparation occurs when the teacher has been brought up to a level where he or she can handle a particular course but has no real confidence or background in it. This is where the interest begins to dwindle. To maintain this interest, some school districts have set up their own inservice programs. They may have preschool sessions for a week or two and then run what boils down to an inservice institute for the rest of the year.

FENNER One other question that nags me about interdisciplinary courses is: "Why is it that so many of the interdisciplinary courses are offered as an experimental sort of thing? Why do they also bow out after a very limited life span?" This hinges directly on the personnel. Sometimes there are one, two, or five men who are interested; and when their interest wanes, the course is changed.

FIASCA There are at least two ways to tackle this problem. Groups such as this, made up of people who have familiarity, knowledge, background, and interest in the field of science education, can sit down and talk about the problems they view as resulting from developing interdisciplinary courses in science. This could lead to a philosophical discussion which would not be resolved for months or years.

I suggest there is another way. People who have an interest and the desire and a strong commitment to interdisciplinary education in science, humanities, and social sciences should be given the encouragement and support to develop courses and try them out. They may fail. Who knows? But we want to use an empirical approach. So far, we really don't have results of experiments that we can pursue with any certainty. I would hope that one of the conclusions of this conference would be the encouragement of any group or any individual, to pursue the development of any kind of structure thought viable by him.

Breaking into the Loop

SHOWALTER We keep telling ourselves that we can't proceed with interdisciplinary science because the teachers aren't ready, the colleges aren't ready and so forth, in a complete loop. Let's try to describe the system of this loop. What is the most vulnerable point at which this closed circle can be broken into?

EISS Wherever there is a loop opening the circle may be broken. This will be at all levels in the educational system.

BURKMAN It is easier than that. If you include training the teachers, you can start with teacher training, you can start with the development of instructional materials, you can aim at the beginning at the trainers of teachers, etc., but some of these are easier than others.

Suppose you were to take the position: "Before we try any interdisciplinary science in the schools, let's try to shape up the teacher education problem." That is probably the most resistant point of all, because, as has been said, the department heads in colleges are going to fight it.

The secondary schools would be less resistant if materials of some sort were to be developed. If no materials are to be produced, an alternative would be to produce an instructional plan and put it in the hands of the teachers. If the plan were reasonable, the chances are teachers would give it a whirl. Once that happened, the idea might get started in the schools. Then let that begin to put pressure on teacher education. If something happens in the schools, you can almost count on the education people to move in that direction. The other way around is not true.

The college level is probably the least vulnerable point at which to introduce this kind of interdisciplinary change. Furthermore, there is another reason for starting at the precollege level. There is more likely to be money available, because the government has become more or less committed to the idea that if you can do something in the schools, then that's the place to break the chain. If money is indeed available, we can find enthusiastic people who want to work on an interdisciplinary science program. You can assume that the schools will be willing to try something that is reasonable. The way to break the chain is to produce something reasonable that you can put into the schools and hope that the rest of the hierarchy will change with time. I am also assuming that the teachers that exist now are well enough trained to implement something that is reasonable.

SHOWALTER Now your assumption is that the immediate stimulus to people in the secondary schools would be some instructional materials? In other words, a package of some sort?

BURKMAN I don't know what it would be, something concrete, but not necessarily books. I can propose a top-of-the-head model for getting an interdisciplinary science course introduced into school programs. Let's assume that a group is formed and told simply, "We want an interdisciplinary science course in the schools; go ahead." Money is available, and all the practical problems are solved. How are these program developers to get under way? The first step, obviously, would be to make a decision as to what they want to do for the students, at least in a general way.

From here on, the developers would have to make some further—and very critical—assumptions. First, they must worry about the teacher. They would have to deal with such matters as these: What is the training of the teacher in the field? What are his capabilities? Second, the physical setting in which their program is going to take place—to what degree will this dictate how much laboratory work to include and what kind of facilities will be needed? Third, what skills and knowledges toward the objectives will the student bring with him? At what level is he? Fourth, and here is one that we often forget: What is the tolerance of the school system for change, particularly in terms of cost?

The group members wouldn't necessarily center upon these four points, but they've got to make some assumptions about them. As an example, let's take the training and capabilities of the teacher. The group could assume that the teachers will not cooperate with anything so drastic and that, therefore, they must aim the program directly at the youngsters. They might assume that the teachers are ready and do not need teacher training. They might assume, on the other hand, that the teachers aren't ready, but they refuse to aim at the student without worrying about the teacher. This means that teacher training will be accented. A corollary to this is the assumption that the teacher is amenable to being retrained.

After the group has made assumptions on the four points, they must identify whatever unifying threads they are going to use as a basis for organization of the content. Determining the sequence, if any, is very important because there is a question as to whether there is any optimal sequence of learning for children.

Once the sequence, if any, has been determined, the next step would be to decide upon the instructional point of view to be embodied in the program. Here, the critical question is: "To what degree should we depend upon the teacher as a primary vehicle of instruction? Related to this is the matter of media. Will the primary medium of communication be the teacher (talk), words written on paper, audio, or video tapes, or what? The medium is critical: If you put the material on paper, you have a reading problem. This might force you into an audio-tutorial approach or something like it. Moreover, there's the question of whether learning will be on a group basis or individual basis—will 30 youngsters be taught the same thing at the same time, or will there be some individualized approach?

Finally, any group will likely run into what I like to call superman versus man concept. Should you find a person like our speaker this morning (Cassidy), who obviously has superior intellectual capacities and a wide range of experiences, and have him work up the course? Or should you have a series of people operating so that the course passes through a superman's editing?

EISS But with Cassidy's course, it was the students as much as the man. These students were so highly selected he could use that technique.

BURKMAN And he was able to react to the students' individual situations. But, in our assumptions we may even decide that the teacher doesn't have to be a super philosopher type. This can be handled in other ways. The specific details of the content to be dealt with can be handled if the teacher's role in the whole scheme is different from what we have now.

Presently, instruction involves giving a teacher a lot of stuff, like films, books, or whatever, and asking him to make essentially all the decisions. He becomes a jack-of-all-trades, who has to decide which materials are best and what is the best sequence in which to present them.

Let's look at instruction in another way, just to illustrate the problem. Suppose the teacher, instead of being the digester of all the material, is parallel to a lot of films, books, tapes that the student has available to him. In such a situation the teacher would be at the command of the student, rather than the student being at the command of the teacher. That kind of role is more difficult for a teacher. It is the kind of role where the teacher essentially is trying to

solve the immediate problems the student poses, and only enters the picture where he is needed. Getting teachers to play that role would be tough to do because the teacher would have to make a big adjustment. I am not arguing for either one of these possibilities. The point is, whichever assumptions you make about the role of the teacher in your program, it's going to call for two different sets of action in developing the program. What we have done up to now is to design a system without considering this sort of thing.

FIASCA As regards the instructional method to be used, the only sensible method is to assume that no one person has the competence to know what is important to know about physics, chemistry, biology, earth science, cybernetics, psychology, and all other subjects. To prepare such a program requires more than one individual. A small committee of three or four different kinds of people, a biophysicist, a biochemist, someone interested in systems, and then perhaps someone interested in psychobiology, will do. These people talk to one another and set forth what is really essential in their fields.

SHOWALTER This has been done.

FIASCA True, what NSTA did in 1961 was precisely this: What are the main and central schemes in science? However, even this was not done by persons competent in the cross-disciplinary fields.

BURKMAN There are probably several levels. There is the blue sky, with a group of people who know the powerfoul things of science, but they will probably reach the same conclusions as those other scientists. The next step is to talk about: Where do we go educationally with these powerful themes, and this is where we have gotten into trouble. Scientists don't easily turn on practical classroom problems or instructional theory but prefer to think in content terms. On the other hand, systems men and psychologists don't know a thing about science. So what we have now in this country are two kinds of developments. We have systems people and psychologists talking to each other, producing science materials, which the scientists criticize with something like "My God, such horrible things!" Then we have science materials being produced by scientists, which the instructional design people criticize with, "My God, why did you go that route?" These people are not likely to be able to talk to each other. There has to be someone who is able to talk to the systems man, the media man, and the content man—someone sitting in the middle.

SCHUBERT I think that what we have to look for are not groups of people deciding what is right, but a great genius who tells us what is the structure of science. The sorry thing is that it does take a great genius to do this kind of thing. For example, look who changed chemistry. In 1952, Linus Pauling wrote a book. Then all the college texts in chemistry changed. Great insight, unhappily, must come from great men. However, a great genius is not going to write the book. He must work with lesser geniuses who can somehow put into practice what he has done.

FIASCA It would be nice if we could identify the genius who had sufficient competence in the areas that we are going to demand—all of the sciences plus systems science, plus perhaps psychology. Who is in a position to understand the structure of each discipline, then integrate this in his own mind, and produce something really significant? I subscribe to the notion that we need to bring together a number of people who have competence in crossdisciplinary areas. We must have biochemists, biophysicists, systems scientists, psychobiologists, etc.

SCHUBERT Although we talk about the interdisciplinary scientists, they are far more specialists than are the scientists themselves. A biophysicist is far more specialized than a physicist, because he's hacked out a very narrow thing for himself. The doing of interdisciplinary science, which is what the biophysicist does, is vastly different than the teaching of interdisciplinary science education.

COSSMAN People who have not been tapped in shaping curricula are the philosopher scientists. There are growing numbers of individuals who are philosophers of science, and they do know the fields well. It's amazing the breadth of science that someone like Thomas Kuhn actually knows. No one has really attempted to utilize their expertise and translate it into a curriculum. I suggest that we start there.

FIASCA Why can't we move in successive approximation? We've done something with chemistry-physics in Portland. We are doing some work with biology-chemistry-physics. Maybe we ought to polish this up in the next few years and then attempt to bring in systems, the social sciences, behavioral sciences, etc., and thus move in successive approximation toward what we really want.

COSSMAN I agree that curriculum is not created, it evolves, so let's begin evolving.

BURKMAN That's fine. I can't agree with you more, but again, decisions are going to have to be made, possibly between the ideas of the scientists and the dollars-budgets of the schools. Somebody has to meld all of these opinions together.

Patch a Floating Ship or Build a New One?

YOUNG In the educational circle we have the high school student, the high school teacher, the pre-service high school teacher, and the college professor. And this circle makes up a 12-year cycle.

HASKELL I'm not sure it is a circle, because some people are not in the circle—the scientists in the disciplines.

YOUNG Good point! The people in the science department don't really care about the preservice education of teachers. They are concerned with the preparation of majors—and that's one of the problems.

KARPLUS We might look at this from a cybernetic view and consider the current need for teachers and the institutions for teacher education as being in the system at a certain stage. We have to estimate their inertia. We have to know to what extent normal negative feedback operates. Then we have to do certain things. First, we must reduce some of the negative feedback which maintains the status quo and then invent some positive feedback that will accelerate deviations in the direction we want. Probably it would be hopeless to think of reorienting the system as a whole. There will be a subgroup of existing faculty members who could become responsive to the positive feedback. They could be encouraged in their interest and

provided with the necessary support, even though others may be untouched and will continue in their narrow ways.

You just have to recognize that everyone in the United States wants to teach the brightest students or the majors. That's where the prestige is. What we need to find is a feedback route that will encourage a fraction of the faculty to break away from this narrow concept of prestige. Some of us are trying to do this now. We must give teacher preparation involvement more effectiveness and attract more recruits to our ranks, without threatening the rest of our colleagues so badly that they will take measures to prevent our being effective, because they think it a threat to their integrity.

HASKELL It would seem that we are a little like a group on a battleship—a big carrier, for example—that is being trained to develop new structures on the carrier as the vessel is proceeding and even fighting battles. These new structures are to make that ship more valuable and more effective. We are not a threat to anybody. We are their salvation, not their threat.

KARPLUS Unfortunately, some people perceive new instruments as a threat rather than as a solution.

HASKELL It is our job to neutralize the misconception.

KARPLUS To begin, it must be obvious that the ship is seaworthy and that it is of the right construction. You can't fight the battle while you reconstruct the ship.

HASKELL We may have to reconstruct the ship because we may be attacked.

HANNAPEL Let that ship go its way and fight its battles and patch it up as best you can, but back in dry dock build a new ship from scratch on a total conception of a new program.

HASKELL You mean a new university?

HANNAPEL Sure, a new university, a new experimental thing. You can't patch certain things if they are really in bad shape.

KORMONDY There may be grave doubts whether the battleship or aircraft carrier is really built to do the job. Perhaps we need a total experimental situation including the training program.

HAUSMAN We have this ship and 5,000 bilge pumps (The National Science Foundation) working at full speed. If you turn off the pumps, the ship sinks.

DROZIN How can we rebuild the battleship to fit our needs? Its construction should satisfy the new goals of high schools, and its operation should be applicable to their real conditions.

HASKELL I'm engaged in one program where we have begun a seminar in which we hope faculty members will take part. This, we hope will result in restructuring certain courses and certain textbooks. You can begin to rebuild the battleship as it floats and as it fights so that it can help the future high school and grade school teachers. We still have to live in the present colleges, and we still have to transform the present schools.

HAUSMAN It might be necessary to set up a pilot project to make it concrete while you are trying to work within an existing system. It might also be appropriate to build into a master program, a pilot operation dealing with the preparation of teachers for such programs, as an integral part of a curriculum project, in addition to what may have to be done on a remedial basis elsewhere. You might have to set up within the college or university an experimental program that deals only with this preparation for interdisciplinary teaching, for example. You might not be able to get this preparation set up in any other way because of the existing departmental lines.

DROZIN We are entering an era of educational revolution. We should reconsider our "standard curriculum" and try to eliminate the mistakes of the past. If we streamline the curriculum of a future teacher, he will be well versed in his science, such as geology, biology, chemistry, physics, and in addition will have a unified approach to all of the sciences. We should try to foster revolution in curriculum development, directed toward satisfaction of the present school needs. We must convince both the colleges and school administrators that times have changed and we need professionally well-equipped teachers if the student is to be prepared for the future. We need teachers who are capable of learning this new interdisciplinary unified approach, and they must get an opportunity to learn it.

WEITZ In the educational enterprise, the preparation of a better product or a different product, does not necessarily result in its acceptance in the same way as happens in the economic marketplace. I get back to the analogy of the battleship and think about some of the barnacles that we have run into in the Earth Science Curriculum Project. which I think can be regarded as an early version of the interdisciplinary effort. At present, the North Central Association of Colleges and Secondary Schools has no minimal requirements for teachers of earth science, although there are about a million and a quarter youngsters in the country taking it. There is a remarkable disinterest about the whole thing, on the part of state education departments, state-supported college educational people, local supervisors, and indeed down to the individual school teachers. The concern of the college science departments that produce these people is remarkably small; interest seems to be in inverse proportion to the number of departments involved. This is the type of problem that faces any interdisciplinary effort.

You have two choices: Either you rehash the curriculum for the professional as well as the prospective teacher, or you set up separate curricula. You have no indication that the budding professional is getting the best either. It might be that one program would be the best for both. It might be that the education department or college will need to set up its own interdisciplinary science curriculum.

PALLRAND I wonder if we don't have to turn to the small college for this work with teachers? In the larger state universities the whole structural system is geared to turning out people who are very much like yourselves, and teaching interest in education is usually playing a losing battle. The smaller liberal arts college does have this tradition in teaching, and its units have a closer association among themselves. We must go where there is opportunity to experiment and to do things.

KORMONDY Having had a number of years of experience in a liberal arts college, I would like to react to this. Your target is a good one, because it seems that the majority of secondary school teachers are prepared in liberal arts colleges. My experience, though, suggests that there is as much rigidity, if not more, along departmental lines, as in

the universities. We have been trying to amass some data on interdisciplinary courses in liberal arts college, and we find woefully few. I don't mean that it isn't possible because it hasn't happened, but the obstacle is there and needs to be worked around, through, or under.

HAUSMAN Before you anoint the liberal arts college, I think you should think on these points very seriously. I have an impression that we have trained scientists, and some of them are teaching in liberal arts colleges. They go there for any number of reasons, not all of them good reasons. Some of them are because that's where they got a job. Some of this professed dedication to the education of youngsters is not very sincere. A lot of the younger people who have just come out of graduate school have their objectives pretty well frozen. They are ostensibly looking at a bunch of youngsters in front of them, but talking to people out there, their peers. They are impressing someone else. A liberal arts college is just full of all kinds of conflicts of that sort.

KORMONDY Well, you can look just as well to the universities where you have eminent people who teach graduate courses. However, another point: More and more of our students are going to state colleges. These schools may have been teacher-training oriented once, but are now trying to overcome their background. Secondary school teachers, by and large, within the time period we are talking about are going to be coming from the state-supported institutions. If we are going to be dealing in reforms, we are going to have to cope with them. The liberal arts colleges may be our leading edge, but they are going to be turning out a smaller proportion of the high school teachers than will be the universities and state colleges.

HAUSMAN I have another observation about: Do we keep on the old aircraft carrier or do we build a new one in dry dock? Let me ask this: Who owns the secondary schools? We don't. We reformers from government, special commissions, and universities and colleges—we don't own those schools. We have to knock very hard on the gate to get a small door open to let us in to take a peek. If we cannot mobilize the mechanisms that make the schools want to let us in and to participate, we may be having a tough job.

YOUNG Perhaps the key to getting in is money from a foundation, which paid for the cost of opening the door, and well-qualified preservice training in the interdisciplinary topics.

KORMONDY True, there are several quite elegant spots on the horizon in teacher preparation. There are people in these centers who are themselves experimenting with these curricula and new methods of getting at teacher training. A number of PhD's are coming out of these programs, and they are exercising an effect on school systems in which they are working.

CASSIDY They need to be brought together, not only to give each other life, but to maintain what they are doing, to show that they have something valuable to keep alive.

KARPLUS How much teacher selection is there by the schools?

HAUSMAN I would say that by and large the schools are not critical about the details of the education their new teachers have. People hire teachers who have satisfied paper requirements and made a favorable impression in a personal interview. It would be a rare school district, department head or whoever, who would be sophisticated enough to ask the candidate if he has had science with a strong interdisciplinary undergraduate education, or has he not? What we have to do is see that the new people coming on the job market should have these qualifications that we consider more satisfactory. I think that they will find jobs and not be particularly discriminated for or against.

PALLRAND Another promising thing that we try to do here and there, is to involve undergraduate students in educational experiments of one kind or another. The aim is to get people interested in teaching who normally have not thought of teaching. Several of these attempts are going on in our area. We feel strongly that we would like to attract another type of youngster into teacher education. As soon as possible, through the summer or on Saturday mornings, we provide freshmen or sophomores experience with students, getting to know them, getting them interested in teaching and working with young people.

KARPLUS Such experiences also would help students find out early enough to be able to change their vocational aims if they are not suited to be teachers. Others who go into the activities as a kind of lark may find a real commitment to teaching.

PALLRAND Once in the classroom, the average secondary teacher is a fairly isolated person. There is no one who really talks physics in his school, and he has to go some place else to find someone to talk to. Whatever his field, he likes to talk to someone about the same thing he is teaching. Interdisciplinary science might break down this isolation.

KORMONDY As for inservice help, there are some good ideas in a recently proposed model of series of centers conveniently located. These centers will be staffed and equipped with some of the equipment which one might expect them to have, but the most exciting part of the program is their availability for teacher use to try out new techniques. On a national scale this kind of scheme could be generalized. We already have some 10 or 12 national regional laboratories or national laboratories. Now whether these should serve as a nucleus for this kind of program, I don't know; we might have a set of regional centers of some sort. Emanating out from these or as satellites, would be another set of centers. These might be at the state level or substate level, and another subset would be right down near the grassroots.

The findings of teachers, other than in the classroom, would have to be built in so that one would have both positive and negative feedback. One would assure that as new materials are developed, the teachers become aware of them through this kind of program. It becomes a built-in part of the everyday, day-by-day responsibility to the school system as the teacher improves. This would be a different kind of thing from those extra hours that a teacher has to take in order to maintain a certificate.

PALLRAND It seemed to me that the state area kind of thing never went any place. When the question of support came up, the center seemed to die. Maybe this is not true nationally. Locally the activities seemed to center around a few persons; and when they were no longer available, the group seemed to ebb.

HANNAPEL I believe Dr. Kormondy is suggesting a type of continual professional development and staff programming and that somehow the influx of new ideas into the system become institutionalized. As for the extra-

institutional structure, when certain institutional means of support were removed, it went away. These frustrations are the frustrations of changing an institution—changing an existing institution. Institutions have inertia, and they are hard to change and move: but they also have a strength and that is a preservation of certain structures that once established are maintained. What we have to concern ourselves with is how to institutionalize these systems, systems with constant renewal. This is the question John W. Gardner keeps asking; for example, in *Self-Renewal*.

HASKELL That could be answered at least on a basis of history. When the scientific revolution began to transmute western Christians from an illiterate civilization into the first technological civilization, scientists had to form an organization outside the university. They founded the Royal Society. Finally the members began to penetrate the universities, and gradually they transformed the universities. It seems to me that everyone here has, one way or another, decided that we must have some organization which would resemble the Royal Society in the sense that it is the shipbuilding yard, you might say, outside the battleship, which then can help the people inside the various battleships to restructure their ships and to build the necessary new devices in them.

PALLRAND Assuming that after a humanities program which has a course or two in physics, the student begins to teach physics. It seems to me that he would have much more perspective about his subject and about his discipline than would the student who went the normal route to more and more and more physics. There seems to be a certain feeling about higher education where the college science faculty feels that it has to protect physics and that teachers as they learn it cannot violate the book in any way.

KRUPSAW This would not follow in an interdisciplinary series because the teacher who is teaching physics is in effect teaching a humanities-flavored physics more than the interdisciplinary course itself.

HASKELL It seems to me that what Dr. Drozin said about an educational revolution was more applicable. High level intelligence, motivated teachers, and pupils, supervisors, and university presidents—aren't these more needed than the run-of-the-mill? This is what motivates people to stand out against their inertia and to feel that they have a mission, that they have friends. This gives *ésprit de corps*, without which you cannot hope to prevail against this vast inertia of the status quo.

DROZIN A nucleus should be formed first. We cannot recommend a change to interdisciplinary science in 30,000 high schools in America. It should be started somewhere and started on a small scale. Teachers have to get the idea of integration of sciences right now and learn the specifics later.

PALLRAND If they don't get that as an undergraduate, I don't know where they ever will pick it up, if they are going to teach integrated science.

KRUPSAW But they must know some science to integrate it.

WEITZ Dr. Cassidy certainly succeeded in pulling a lot of material together in an integrated way in the course he described. If the students are going to use that information in quite a different way, then our preservice teachers also should be able to adapt it.

KORMONDY I am not sure that there is any information to back that up. We don't have any information that says the teacher who goes through a unified science program makes for a better teacher of unified science. Another dimension of any project in interdisciplinary science should have a very strong evaluation component built into it.

YOUNG Prospective teachers should be sensitized to several things: sensitized to science, to the kind of senses that have been described here, and sensitized to that person who is out there to learn. One of the outcomes I would anticipate among many others, in the behavioral side of teacher preparation, is enabling the teacher to become aware of where his students are at all times. We don't now build this sensitizing training into the teacher preparation program.

DROZIN If we are going to deal with the department of education, we should present our educators with a set of educational objectives. This is what they require, and we should comply. A group needs to zero in on a particular thing and spend some time concentrating on that particular topic. We should develop programs of integration of sciences, then build into those programs a well-articulated set of objectives.

KORMONDY There has been a tremendous emphasis in the preparation of the secondary school teacher, relative to content. We ought to put a good deal of concern on the preparation of any teacher, including the college teacher, and on the attitudes toward what they are going to teach.

YOUNG Indeed, one of our major concerns at this moment is the lack of preparation of the college teacher to teach college.

KORMONDY Last spring, we did a survey of the schools that produced the bulk of PhD's in biology. About 70 percent of all PhD's in biology end up in college teaching. When we did the survey, only 7 of these 150 or more graduate schools had anything approximating a preparatory program for the teaching of biology.

REPORTS FROM DISCUSSION GROUPS

Following the general discussions, one series of group meetings was asked to summarize views on certain topics. These are presented here.

Teacher Education

Report given by JAY YOUNG

We considered themes in terms of teacher science education. There are three points we might make. One centers around the fact that all institutions and students have inertia. It was suggested that a cybernetic analysis with a view to trying to encourage feedback might be a good way to encourage change. Questions were also raised about who "owns" the secondary schools. It certainly is not the reformers; those who would change the curricula need to find ways to open doors. To bring about change in programs, we will need money, from the foundations for example; we will need well-qualified, preservice-trained applicants for positions; the blessing of the state departments of education; and most important of all, a good program, in itself. Another important aspect of inertia is that different science departments in universities tend not to cooperate with each other in interdisciplinary projects.

This leads to the second major point: Perhaps the education departments among the universities could set up their own interdisciplinary schedules for preservice training of teachers. It was suggested that the methods professor must, however, know the science as a scientist rather than as a person who is primarily able only to teach methods in the general sense.

The content of the preservice course should not be the same as it is for a particular science major, yet it must attract students to enroll in it. Might there not be some way of decreasing the multiplicity of courses that might at first be thought necessary? We heard some interesting suggestions about "advanced" elementary physics and "advanced" elementary chemistry, and so on. As an example—the elementary physics course certainly treats the mechanics of physics with Newton's Law, and that is about where it leaves us. The advanced elementary physics would look at Newton's Law again, but it would be in a higher frame of reference—how Newton's Law is related to Schroedinger equations and to Hamiltonians, which tend to unify much more than just Newton's Law. Then, of course, there were suggestions for unifying concepts, one being the cybernetic principle of Mr. Haskell. We discussed whether it is really true that a unifying science preservice curriculum would produce a better interdisciplinary science teacher than might be produced in some other curriculum. It was suggested that research to answer questions of this sort be an integral part of any project on teacher preparation for interdisciplinary science.

Task Force Model

Report given by VICTOR SHOWALTER

We directed our attention to the question: How should a belief in the potential value of interdisciplinary science be implemented? Once we convince ourselves that an interdisciplinary type of science approach in the secondary school is worthwhile, what should be the logical next step to make that a reality on a large scale? A plan to bring this about occupied a major part of our discussion.

Whenever we get into implementing change like this, whenever we discuss such schemes or a vertical thread around which to organize such a curriculum, groups are notoriously ineffective. At my particular organization a group of 12 of us spent about sixteen months trying to identify the ideal organizing theme and the way to approach implementing a unified science curriculum. It has been very slow, and we have relatively little to show for our efforts. In our discussion group here, we decided that what we really need, as Leo Schubert suggested, is some great genius to do for unified science what Pauling did for chemistry back in the early fifties. Realistically, we are willing to invest our hopes in persons of "second-level" genius. We would like to propose that a five-to-eight man team of such persons gather ideas by talking to scientists, to students, to psychologists, to teachers, and to current curriculum directors. This would give us some entry into their various areas of talent, and this could be synthesized into one project activity.

We would see these five or eight or x number of individuals taking a year each to investigate, with the school resources behind them, and at the end of that time, they would present five or eight specific plans for implementing unified science in a developmental project. In other words, each would think independently and individually. They would certainly interact with each other, but they would be housed separately. They would have desks in different places, and so each would operate essentially an independent activity. These people were named "preceptor synthesizers" because they first have to perceive possibilities and second, synthesize these possibilities into a logical plan. They should be willing to volunteer more than one year to the project because the most logical person to direct any project that was proposed in this year would be one of these people or the person who proposed it.

We then talked about the selection of these people. The first cutting would be largely by individual application. An open invitation would be issued; the person could nominate himself and present whatever credentials he thought were appropriate for the task. Whatever funding agency provided the money for this particular effort would devise some way to make a final selection.

This, then, is our basic model: A five-to-eight person team, to come up with specific proposals for action at the end of one year. This, of course, is the initial

stage of developing a curriculum. The next step is the design and development aspect. Then, within the next year or so, it could be put into action.

BURKMAN Anyone who has ever tried to do anything like this knows the theoretical and practical problems. To design a curriculum for interdisciplinary science has to include more than just identifying what the content is. There are some assumptions one has to make about the setting in which this is going to be done, and also there are some new instructional techniques to be considered. All these have to be considered before one starts to do something.

Creating an interdisciplinary program will be considerably more difficult than producing one in physics or chemistry, because the variables are that much more numerous. Therefore, it would be very wise for someone or some group to get the best input possible in all of the dimensions that have a bearing, before setting forth. Such a plan as the one proposed would ensure the availability of the best kind of input that one could have. Certainly the preceptor synthesizers should be free to make selections, but they should process everything that is potentially important and reject what they want to reject on the basis of some rationale. Before the preceptor synthesizers begin synthesizing, be sure that they receive the greatest amount of input possible; make available to them resource people whose brains process ideas differently. The constraint on each preceptor synthesizer would be after all this input to devise some kind of operational plan. Hopefully, more than one plan would result, at least two or maybe even a multitude of plans. This would give the funding agencies optional plans to look at and to choose among.

There is no reason why our preceptor synthesizers shouldn't interact whenever they want to; there would not be walls between them. The thing that would separate them is their purpose: to develop their *own* plans, not the consensus of one plan by the group. There might be some similarities between them, but hopefully, we would have different processing going on with the same information, and different plans evolving.

DITTMER The proposed preceptor synthesizers and the development of an interdisciplinary program must be cognizant of the existing schools, the teacher, and teacher preparation. I would suggest that while the group of preceptors and designers are working, some grassroot project development be encouraged. This would give the group of "dreamers and planners" a chance to interact with a group of "doers." This simultaneous effort would permit an evaluation of objectives and developments. It would accelerate the production of a realistic program; in fact, a particular project might be ready to go at the end of a year's time. Otherwise, I'm afraid we would be waiting to stimulate someone out of the preceptor-designer team or someone from the group assembled here to implement the ideas. There is always the danger of planners getting tired and frustrated after working in the abstract for a whole year.

SHOWALTER Certainly, other approaches should not be discouraged; this should not be the only approach.

FIASCA I started with this group, and for the most part, I think the plan presented is viable. However, I would like to express some concerns. The first relates to the subgenius or the one person who might be the final voice for the project. Will one person have the ability to take knowledge and experience from a variety of sources? Will he have the ability to integrate this in such a way that he can propose a course content development that we will all accept? When it comes to implementing ideas, it is difficult for one individual, after he has thought up some sort of framework in terms of course content, to say to a group, "Here is my idea, now you implement it. You take this structure, and you devise courses and move those courses out into the public schools." I worry about that.

CASSIDY We are faced with the following kind of difficulty. We will probably agree on the curriculum, more or less, for it seems that there are large areas of agreement, and people who are giving interdisciplinary courses largely end up with about the same kind of courses. That is because they are reasonable, and they find reason for the problem. I don't see any great difficulty here with respect to content, and I wouldn't go around asking too many people about content, because most of the really outstanding specialists have not thought about content unless they have actually been forced to teach a course.

What one really should do is to go around and talk with principals and superintendents and probably question these and others in administrative positions. They can create a wave of implementation of interdisciplinary programs.

That I would suggest, plus one other thing: We are woefully lacking in good technology in this area. I realize when I am giving a course, that if I applied what is known about communication levels—just technology and ability to communicate—I could communicate twice as much. Or I could communicate more than I do now with more impact, with better learning results, and so forth. I don't know enough about the technology because I've been so busy trying to learn content that I haven't gotten to the new techniques of communication. Money counts, too: I don't have the money to buy the techniques of presentation. For one good lecture, it may take 40 or 50 hours of work with an expert communications man, a movie maker, or a TV tape maker. Your team would do a tremendous service if it could bring us this kind of communication facility.

If we have confidence in ourselves as teachers, it doesn't really make that much difference what the specific content is, because it can be good science on the basis of what you are interested in. We should worry about the overall general philosophy of the student.

SHOWALTER Then perhaps what should be elicited, instead of just the particular content, would be the content that is implicit in the nature of science. These perceptors would be personally sensitive to this criterion.

KORMONDY Let me restate the recommendation: It is that a group of five to eight individuals be supported for one year as individuals, but with the opportunity to interact with each other at selected intervals, to present, at the end of this year, a plan (or plans) whereby a unified science curriculum can be designed and developed.

SCHUBERT This plan envisages conversation in some structured way with the super-type genius, but also would bring in behavioral people, humanists, social scientists, communications people, and so on. All of this would be pulled together in some way so that a viable interdisciplinary program could be developed.

The Breadth of Unity

Reported by
FRANCIS M. POTTENGER, III

Our group was given the charge of considering the breadth of interdisciplinary unity that should be reflected in any new interdisciplinary program. We began by describing the student target, the intellectual needle, through which the thread of any new program would be drawn. It was generally agreed that a feel for the holistic integrity of science should be part of the educational experience of *all* students. This is the kind of experience needed by both the science-oriented and the terminal science student. Further, it was felt that to gain this integrated view, the school must allow an exposure time of at least three years.

Turning to the content thread, it was agreed by all that the spinning of this thread should be done principally through the experience of laboratory and field investigation. Science presented through the vicarious experience of words and visual stimuli denatures an enterprise rich with tactile and other sensory experience.

Communication skills necessary to understand the discourse of science were singled out for special attention. Members speaking for both physical and biological science emphasized the importance of the student's being able to gain meaning from the mathematics of science. Mathematics has become one of the major integrating conceptual tools employed throughout contemporary science.

It was agreed that attention must be given to the development of the skills associated with both the reading of the literature of science and the verbal communication of scientific information. The student should become an independent acquirer of knowledge. In his lifetime, information about developments within the sciences will come through a mixture of media—written, spoken, and visual. The student should be able to respond effectively to all of these.

Content that has special potential for communicating a sense of unity was explored. Though no attempt was made to produce an exhaustive list, the following four general categories were considered as essential:

1. The interaction of science with the wider societal community
2. Knowledge of the environmental sciences
3. Systematizing theories and methods that have drawn the physical, earth, and biological sciences together
4. An understanding of the physiology of the animal, man

The group felt that it would be impossible for a course attempting to emphasize the unity of science to neglect the impact of the sciences in the wider social arena. Science in application of itself is unifying since much of modern technology transgresses normal disciplinary boundaries. How better can the theoretical contributions of the various sciences be focused than in the consideration of the solution to the modern problems of environmental quality?

In the selection of subject matter, no area of scientific study is more unifying than the study of ecology and the array of associated environmental sciences. These disciplined ways of thought look at nature as a unified whole and instrumentally draw on all other areas of scientific thought.

It was noted that the approach to ecology should not be prejudiced by any one discipline. The input of each disciplinary area should be presented from the perspective of the whole. Emphasis was placed on the importance of incorporating historical study of the evolution of the grand environment of the universe as well as terrestial environments.

It was the consensus that unifying methods and theories that have guided the mainstream of scientific inquiry should make up the major content of the program. The observation was made that science has developed out of fact; that mastery of certain salient facts is necessary to the understanding of more abstract constructs. There is a place for rote memory of basic fact, for it is meaningless to speak of broad understanding of science without rooting that understanding in factual particulars.

The student's own biological nature provides a special intellectual link with the rest of the living world, giving a unifying center to the inputs of many areas of investigation. In the study of common biological structures and functions the student can gain experience with living models that describe the physiological boundaries within which he as an individual can maintain an optimal life state. In this focus, the disruptive influences of disease, drugs, dietary deprivation, contamination and pollution, and populational growth can be personalized.

Finally, it was agreed that the program should be structured to take advantage of the best thinking of educational psychology. The program should move from the concrete and factual to the abstract. All work should be supported by evaluational mechanisms which can give immediate feedback concerning the degree of success of the program.

It was generally felt that a three-year curriculum incorporating the unifying elements outlined would greatly enhance the understanding of coming generations of the full fabric of the scientific endeavor.

The Sense of the Meeting

A statement prepared
by several participants

1. There is need for interdisciplinary instruction in science. Szent-Györgyi pointed out that threats to our survival and the progress of our educational institutions require urgent action toward interdisciplinary instruction in science.
2. Programs in interdisciplinary instruction in science are being developed more or less independently in this country.
3. In the interest of all education at all levels, it would be desirable to find the areas that overlap so that each validates the other.
4. If an overall organizing scheme were available, it should be investigated as a possible intellectual framework from which to organize interdisciplinary instruction.
5. The urgency of the crisis recommends that government and private funding agencies pay serious attention to the above statement.

Proposal for a Broader Meeting

A motion was made by Kormondy and passed that an interdisciplinary meeting on a wider base, including teachers in secondary schools, colleagues in the social sciences and humanities, and so on be brought together for an interdisciplinary meeting.

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